RESEARCH PROGRAM TO DEVELOP ALLOYS

FOR UP TO 1200°F STRAIN GAGES

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TABLE OF CONTENTS

I. INTRODUCTION

II. OBJECTIVES

III. PROCEDURE

IV. GRAPHICAL RESULTS

V. STRAIN GAGE DESIGN

VI. STRAIN GAGE EVALUATION

VII. CONCLUSIONS

VIII. RECOMMENDATIONS

I. INTRODUCTION

Our rapidly expanding technology has brought forth numerous systems which perform in high-temperature environments. It is necessary to qualify materials for these systems and subsequently evaluate the performance of prototype and production units under operating conditions.

We must be concerned about the effects of temperature on the properties of these materials, especially when resulting changes might jeopardize specified performance of the materials in system components. Of primary concern is temperature dependence of mechanical, physical, metallurgical and electrical properties. The challenge in developing measuring devices and methods to evaluate high-temperature behavior arises from the fact that these devices are themselves subject to the same effects.

In 1957 when the temperature compensation of electric resistance strain gages was first introduced in practical terms, structural evaluation at other than ambient or low temperature conditions became more simple and accurate by an order of magnitude. It became possible to measure static strains accurately up to 600°F, even in the presence of thermal gradients. Soon, however, the development of high energy power systems and the resulting advent of space exploration placed even greater demands upon measuring devices. One of the most serious needs was for a strain gage which could be used reliably for static measurements above 1000°F. This need has persisted to the present time in the face of considerable development effort which has yielded only partial solutions to the problem.

The essential requirements for a resistance strain gage alloy suitable for the measurement of steady state strains at 1200°F are:

1. Metallurgical stability at elevated temperature
2. A specific resistance of at least 200 Ohms/CMF
3. An apparent strain with temperature no larger than the applied or mechanical strain
4. Constant (or linear) temperature coefficient of resistance
5. Only moderate change in gage factor with temperature
6. Coefficient of expansion (PPM/°F) compatible with high-temperature structural materials
7. Only moderate change in gage factor with strain
8. Adequate mechanical strength

In order to meet the above requirements, "building blocks" were selected for the design of strain gage alloys (Table I). The investigation reported herein does not exhaust the possibilities for new alloys from this group.

Table I

Elements for Design of Strain Gage Filaments

Element	Atomic Number	Melting Point °F	Resistivity Ω/CMF	Temperature Coefficient μΩ/Ω/°F	Thermal Expansion με/°F	Modulus of Elasticity 10^6 lb/in^2	Oxidation Temperature °F
Al	13	1220	16	2400	12.9	10	400
Ti	22	3270	300	3000	4.8	15	500
Cr	24	3350	78	1700	4.0	36	800
Mn	25	2268	260	110-180	12.7	23	70
Fe	26	2795	60	3400	6.4	29	600
Co	27	2715	38	3700	6.8	30	575
Ni	28	2650	50	2700	7.3	30	1100
Cu	29	1981	11	2200	9.2	16	600
Mo	42	4750	30	1800	2.7	50	400
Pd	46	2830	60	1800	6.4	17	1300
W	74	6120	33	2500	2.4	53	300
Pt	78	3224	59	1700	4.9	24	2200

II. OBJECTIVES

The present research and development program was undertaken with a threefold purpose:

1. Develop satisfactory alloys for temperature compensated strain gages for the measurement of steady-state strains up to 1200°F.
2. Critically evaluate these alloys in actual strain gage configurations, taking into consideration necessary refinements in the entire measuring system, e.g., adhesives, lead-in wiring, protective coatings, instrumentation, etc.
3. Produce sufficient quantities of these alloys and associated materials to permit fabrication of initial production quantities of gage systems.

III. PROCEDURE

In pursuing the objectives of this investigation, fifteen alloys were melted and wire samples drawn, having diameters of 0.005", 0.002", 0.001". One alloy was reduced to foil having a thickness of 0.0004" and 0.0002".

Pertinent strain gage properties of each of these alloys were determined for various conditions of heat treatment. Three nickel-base "Superalloys" were tested (Table II). The iron-base "Superalloy" evaluated is listed in Table III. A cobalt-base "Superalloy" also was tested (Table IV). Numerous precious-metal alloys of platinum were selected for evaluation (Tables V, VI, and VII).

The alloys selected were vacuum melted and samples were reduced to fine wire and foil by qualified sources. The evaluation of the alloys was conducted at the Detroit facility of William T. Bean, Inc. (Figures 1 and 2) Strain gages were fabricated from each alloy (Figures 2 and 3) and mounted on test specimens (Figure 4).

An improved ceramic cement (H-1) was used as the bonding agent. Nichrome ribbons were used to connect the strain gage filament to lead-in wires. All connections were spot-welded. Stainless steel-clad copper wires with fiberglas insulation were used in the conventional 3-wire circuit. The completed installation was coated with a white protective coating (Gagekote # 1) in order to reduce radiation effects at elevated temperature. The test specimen was wrapped in several layers of thin fiberglas cloth in order to assure uniform heating and cooling.

Test results are summarized in Tables II through VI. Significant characteristics are graphically presented in this report by the extensive use of an X-Y Recorder, for example, the Resistance vs. Temperature Curves shown in Figure 5.

The E.M.F. of a chromel/alumel thermocouple was used to drive the X-Axis of the Moseley Recorder. The thermocouple output was simultaneously monitored by a Doric DVM.

Table II

<u>Nickel-Base Alloys</u>

No.	Alloy	Ω/CMF @ 100°F	Gage Factor	% ΔR @ 1100°F	% ΔR/100°F	μΩ/Ω/°F	Apparent με/°F	Notes
16	Nichrome V 80 Ni 20 Cr	650	2.1	4.0	0.4	40	19	Not stable
7	Inconel 102 67 Ni 15 Cr 8 Fe 3 Mo 3 W 3 Cd	662-771	2.2	3.2-3.6	0.32-0.36	32-36	15-16	Not stable
8	Hastelloy N 67 Ni 17 Mo 7 Cr 5 Fe	606-755	2.3	4.0	0.4	40	17	Not stable
5	Rene 41 54 Ni 19 Cr 11 Co 10 Mo 3 Ti	710-816	2.3	1.5-4.5	0.15-0.45	15-45	7-20	Not stable

Table III

<u>Iron-Base Alloy</u>

No.	Alloy	Ω/CMF @ 100°F	Gage Factor	% ΔR @ 1100°F	% ΔR/100°F	μΩ/Ω/°F	Apparent με/°F	Notes
9	N-155 30 Fe 21 Cr 20 Ni 20 Co	591-625	2.4	20.5	2.05	205	85	Not stable

Table IV

Cobalt-Base Alloy

No.	Alloy	Ω/CMF @ 100°F	Gage Factor	% ΔR @ 1100°F	% ΔR/100°F	μΩ/Ω/°F	Apparent με/°F	Notes
6	S-816 44 Co 20 Ni 20 Cr 4 Mo 4 W 3 Fe	555-610	2.0	13.5-15.5	1.35-1.55	135-155	65-75	Not stable

Table V

Alloys of Platinum-Copper

No.	Alloy	Ω/CMF @ 100°F	Gage Factor	% ΔR @ 1100°F	% ΔR/100°F	μΩ/Ω/°F	Apparent με/°F	Notes
1	80 Pt 20 Cu	220-340	2.0	25	2.5	250	125	Not stable
15	80 Pt 15 Cu 5 Ni	440-444	2.1	15	1.5	150	71	Some instability above 1000°F
10	80 Pt 15 Cu 5 W	Not workable		5	.5	50	---	Not stable
2	90 Pt 8 Cu 2 W	320-344	2.4	20	2.0	200	83	Some instability above 1000°F
12	90 Pt 5 Cu 5 W	Not workable		22	2.2	220	---	Unstable above 1000°F

Table VI

Alloys of Platinum-Nickel

No.	Alloy	Ω/CMF @ 100°F	Gage Factor	% ΔR @ 1100°F	% ΔR/100°F	μΩ/Ω/°F	Apparent με/°F	Notes
14	90 Pt 10 Ni	192	4.2	63	6.3	630	150	Good stability to 1400°F
3	90 Pt 8 Ni 2 W	188	4.2	68	6.8	680	162	Good stability to 1400°F
4	90 Pt 8 Ni 2 Cr	228	4.1	44	4.4	440	107	Good stability to 1400°F
11	90 Pt 5 Ni 5 Cr	Not workable		170	17.0	1700	---	Erratic above 700°F
15	80 Pt 5 Ni 15 Cu	440-476	2.1	15	1.5	150	71	Unstable above 1000°F

Table VII

Alloys of Platinum-Tungsten

No.	Alloy	Ω/CMF @ 100°F	Gage Factor	% ΔR @ 1100°F	% ΔR/100°F	μΩ/Ω/°F	Apparent με/°F	Notes
13	92 Pt 8 W	330-355	5.3	21	2.1	210	40	Good stability to 1400°F
2	90 Pt 2 W 8 Cu	320-344	2.4	20	2.0	200	83	Not stable above 1000°F
3	90 Pt 2 W 8 Ni	188-210	4.2	68	6.8	680	162	Good stability to 1400°F

FIGURE 1. STRAIN GAGE EVALUATION LABORATORY

FIGURE 2. STRAIN GAGE FABRICATION & INSTALLATION AREA

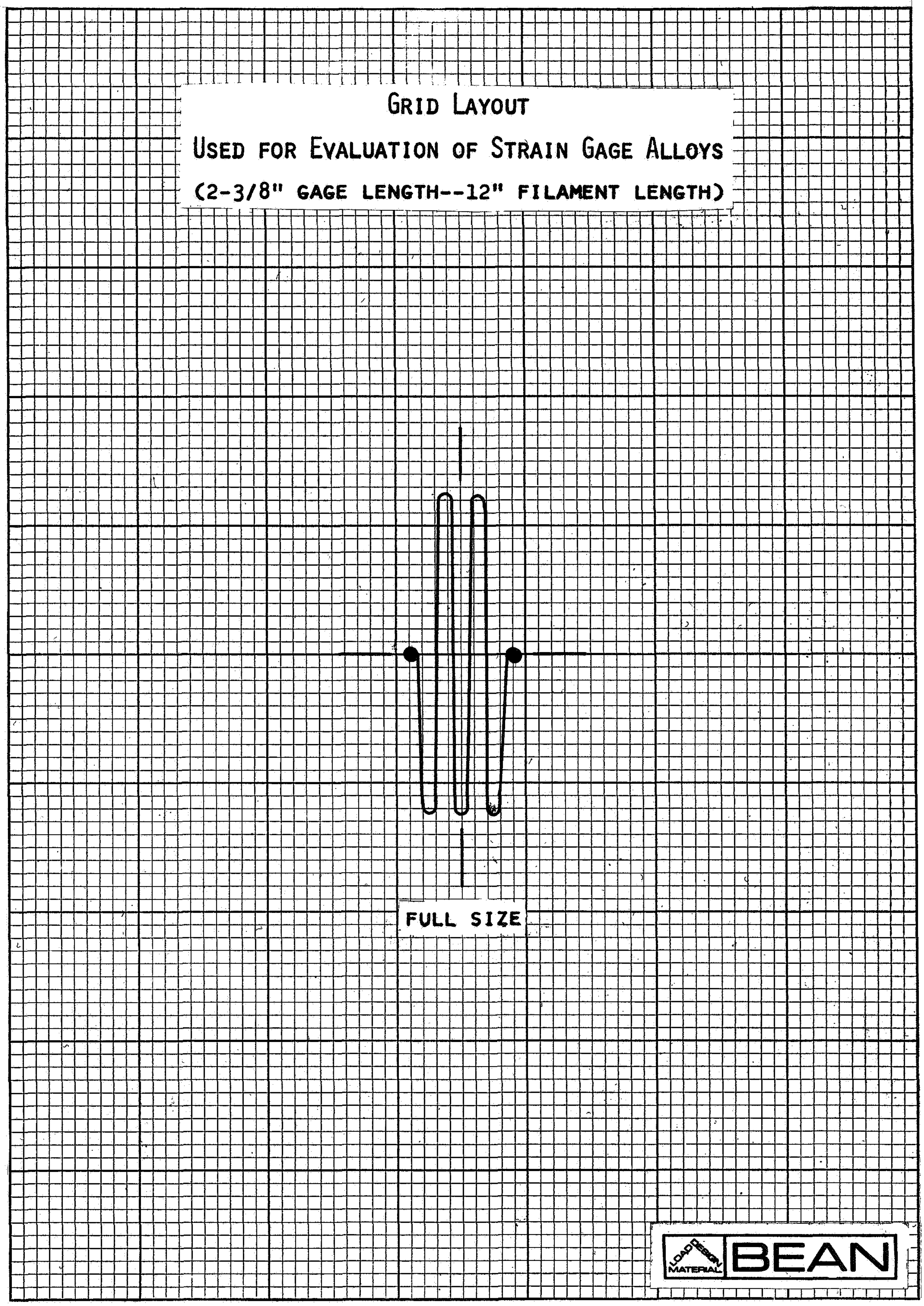
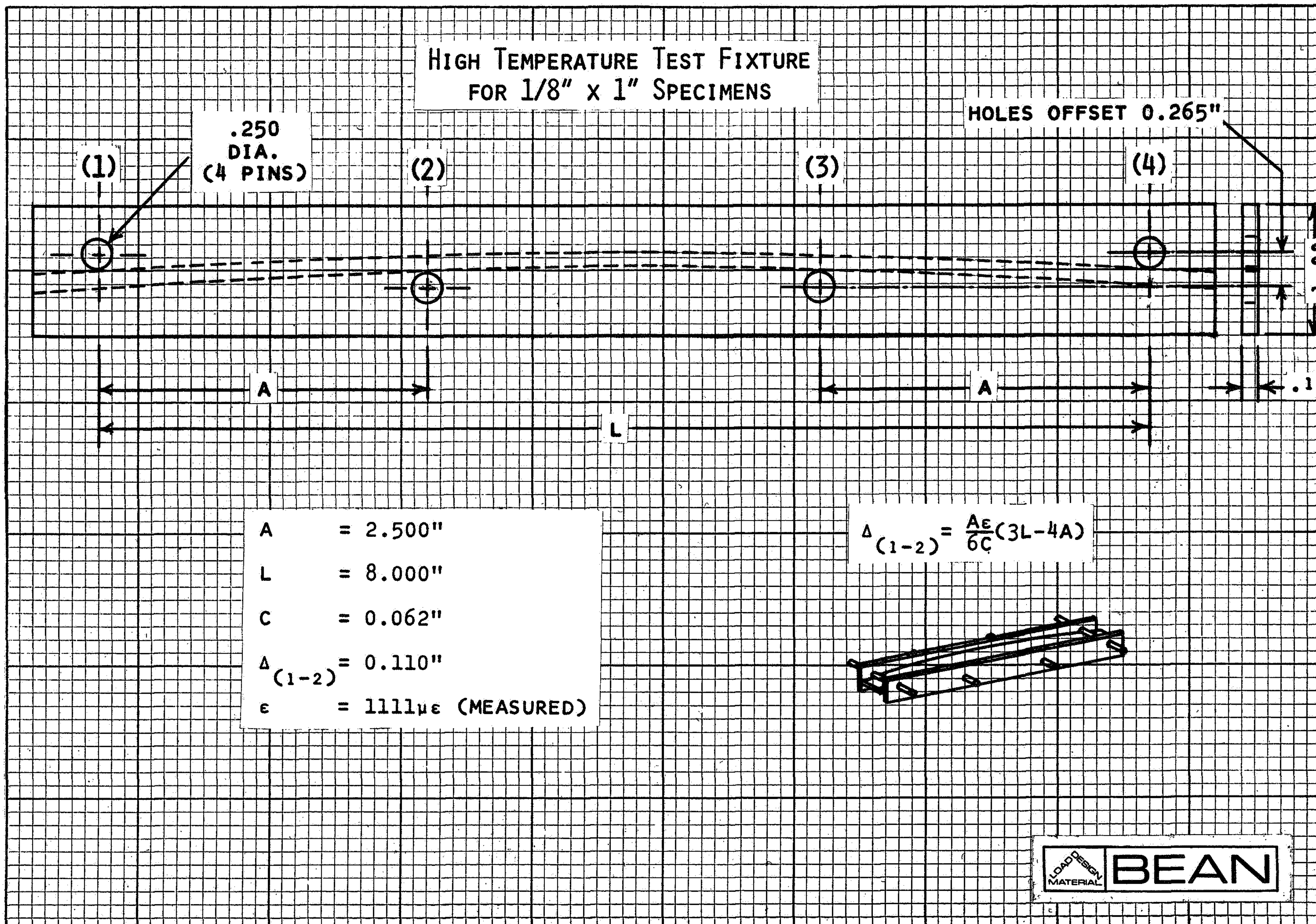
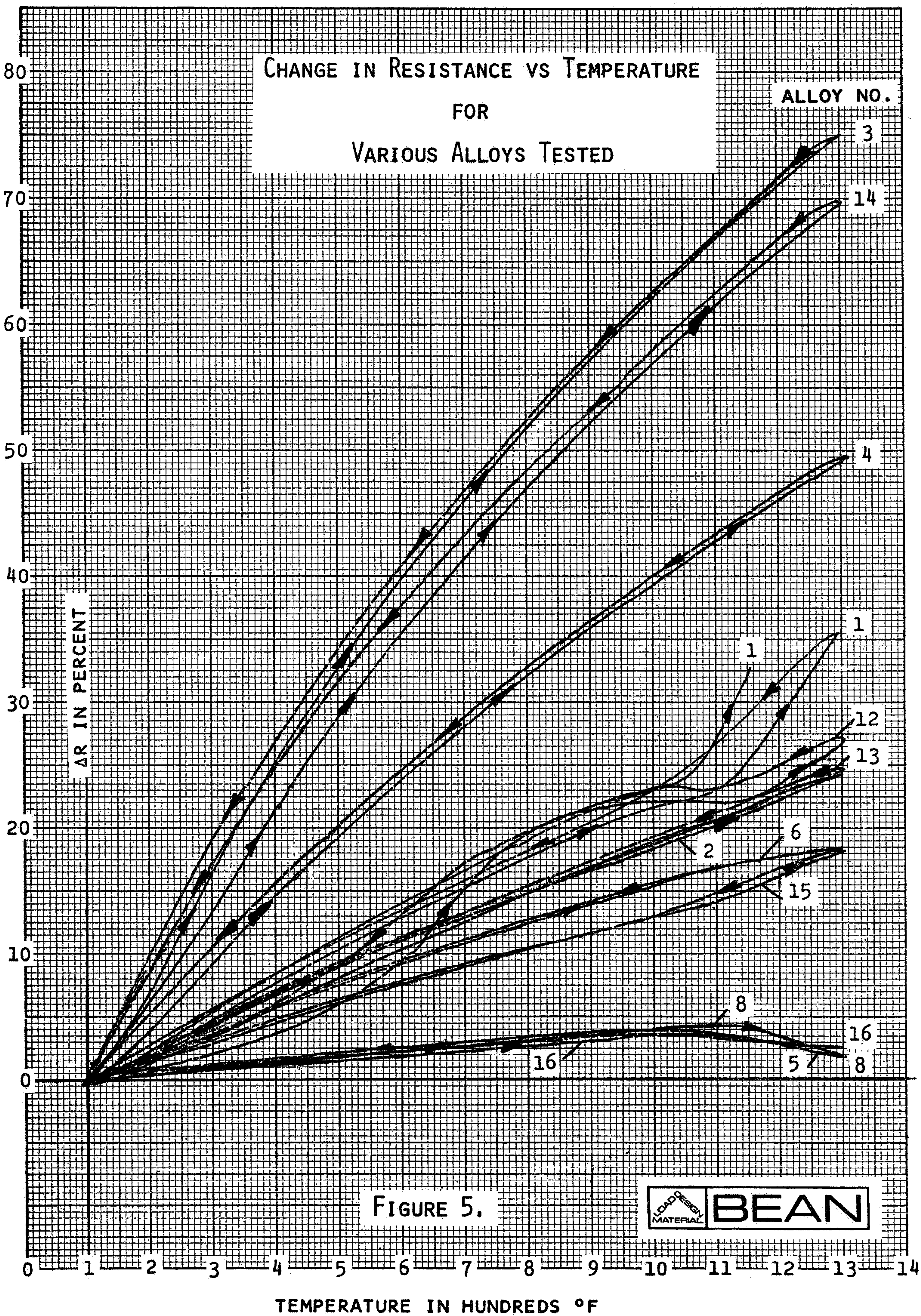

GRID LAYOUT
USED FOR EVALUATION OF STRAIN GAGE ALLOYS
(2-3/8" GAGE LENGTH--12" FILAMENT LENGTH)
FULL SIZE
LOAD DESIGN MATERIAL
BEAN

FIGURE 3.



HIGH TEMPERATURE TEST FIXTURE
FOR 1/8" x 1" SPECIMENS
.250
DIA.
(4 PINS)
HOLES OFFSET 0.265"
(1)
(2)
(3)
(4)
1.00
.125
A
A
L
A = 2.500"
L = 8.000"
C = 0.062"
$\Delta_{(1-2)}$ = 0.110"
ε = 1111$\mu\varepsilon$ (MEASURED)
$\Delta_{(1-2)} = \frac{A\varepsilon}{6C}(3L-4A)$
LOAD DESIGN MATERIAL BEAN

FIGURE 4.



CHANGE IN RESISTANCE VS TEMPERATURE
FOR
VARIOUS ALLOYS TESTED
ALLOY NO.
3
14
4
1
1
12
13
2
6
15
8
16
16
5
8
ΔR IN PERCENT
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
TEMPERATURE IN HUNDREDS °F

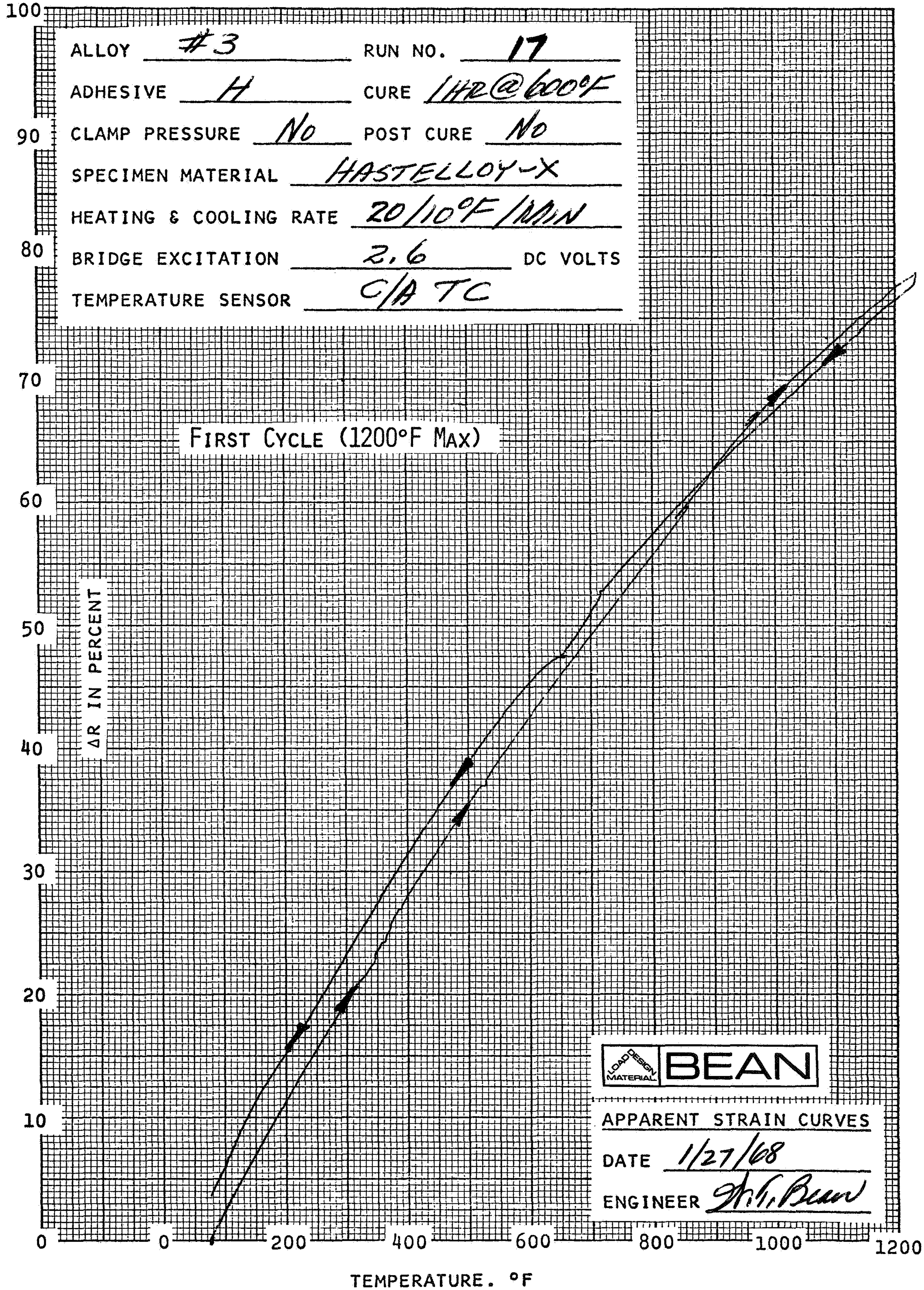
FIGURE 5.

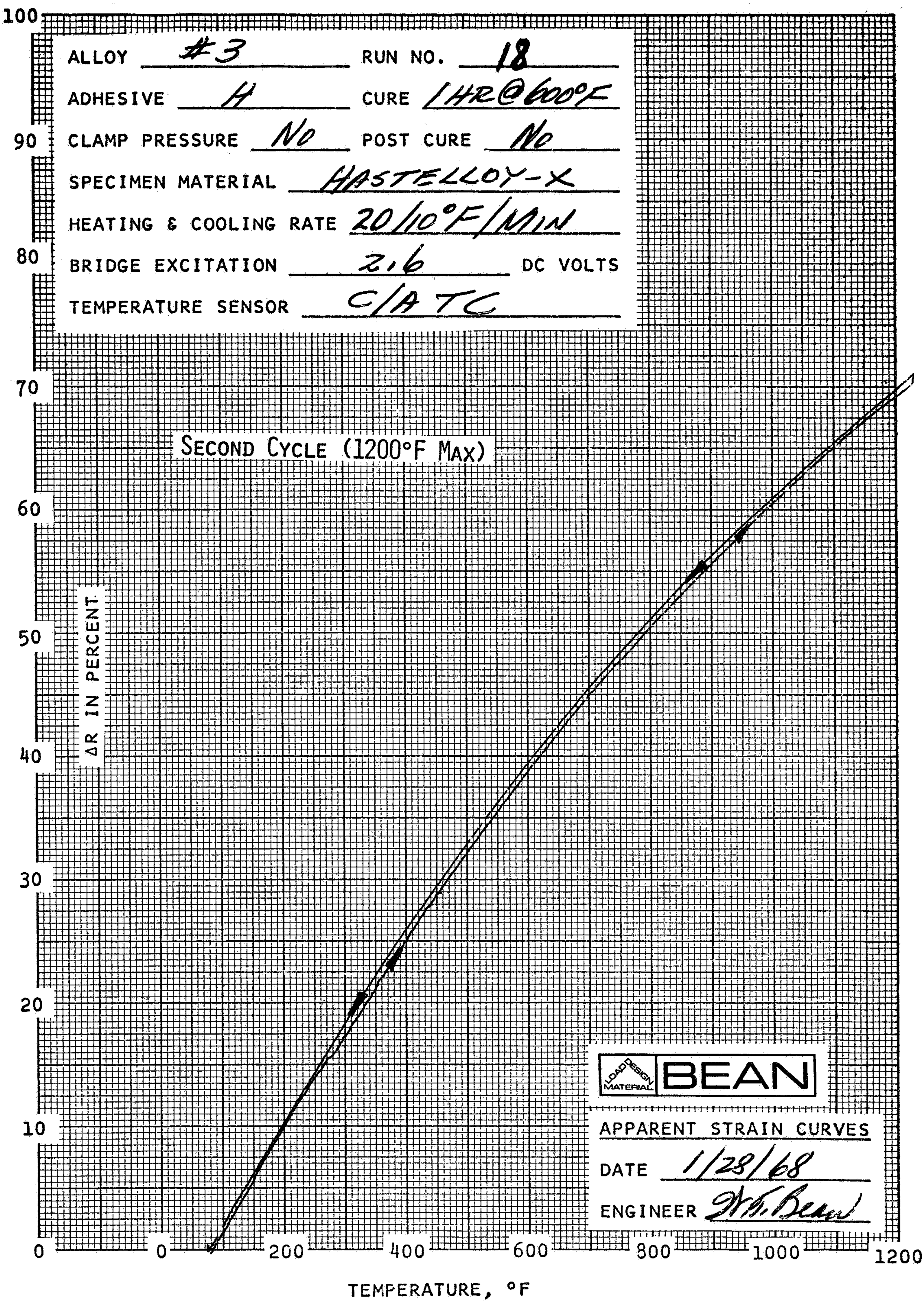
IV. GRAPHICAL RESULTS

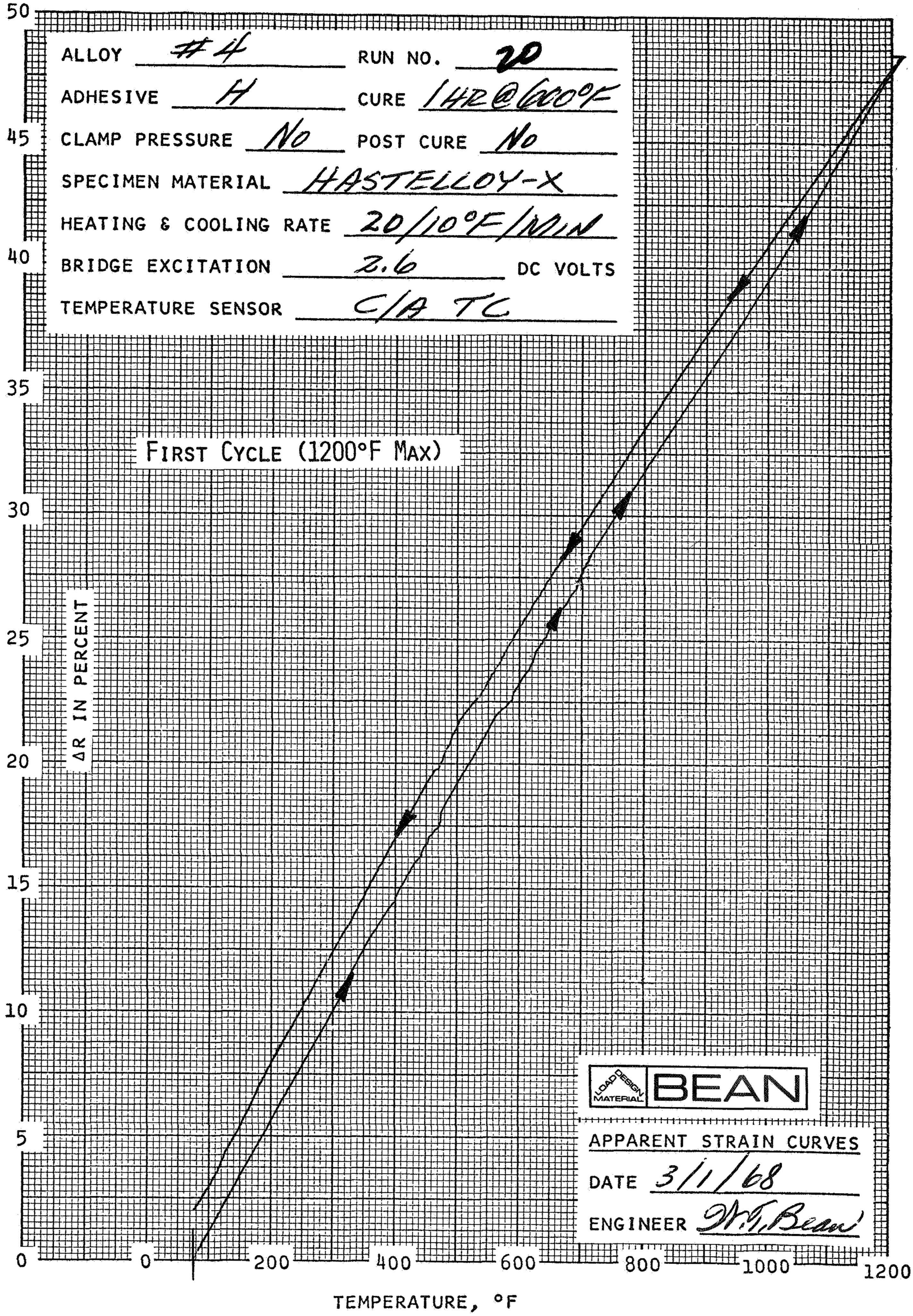
Of all the strain gage materials tested, only three alloys of platinum exhibited satisfactory stability up to 1200°F. Curves showing the first and second heat cycles to 1200°F for these alloys follow (Runs # 17, # 18, # 20, # 21, # 100, # 101). Typical Resistance/Temperature/Time Curves on a high strength nickel-base alloy are shown (Runs # 23, # 27, # 29, # 62, # 160, # 161, # 163 through # 167). Figure 6 combines Runs # 60 and # 61 and indicates the apparent strain from -320°F to +950°F.

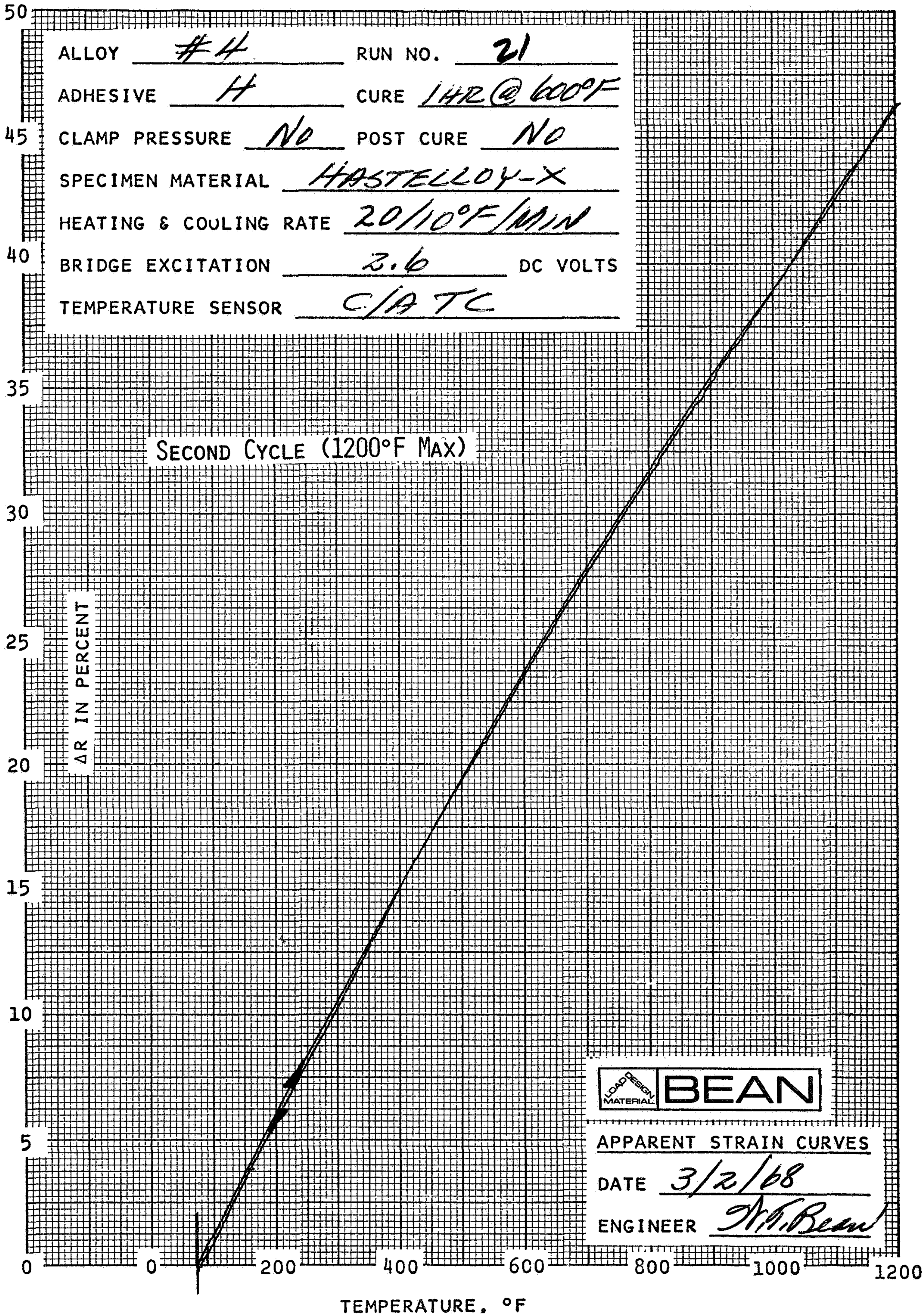
Test results on the other alloys follow:

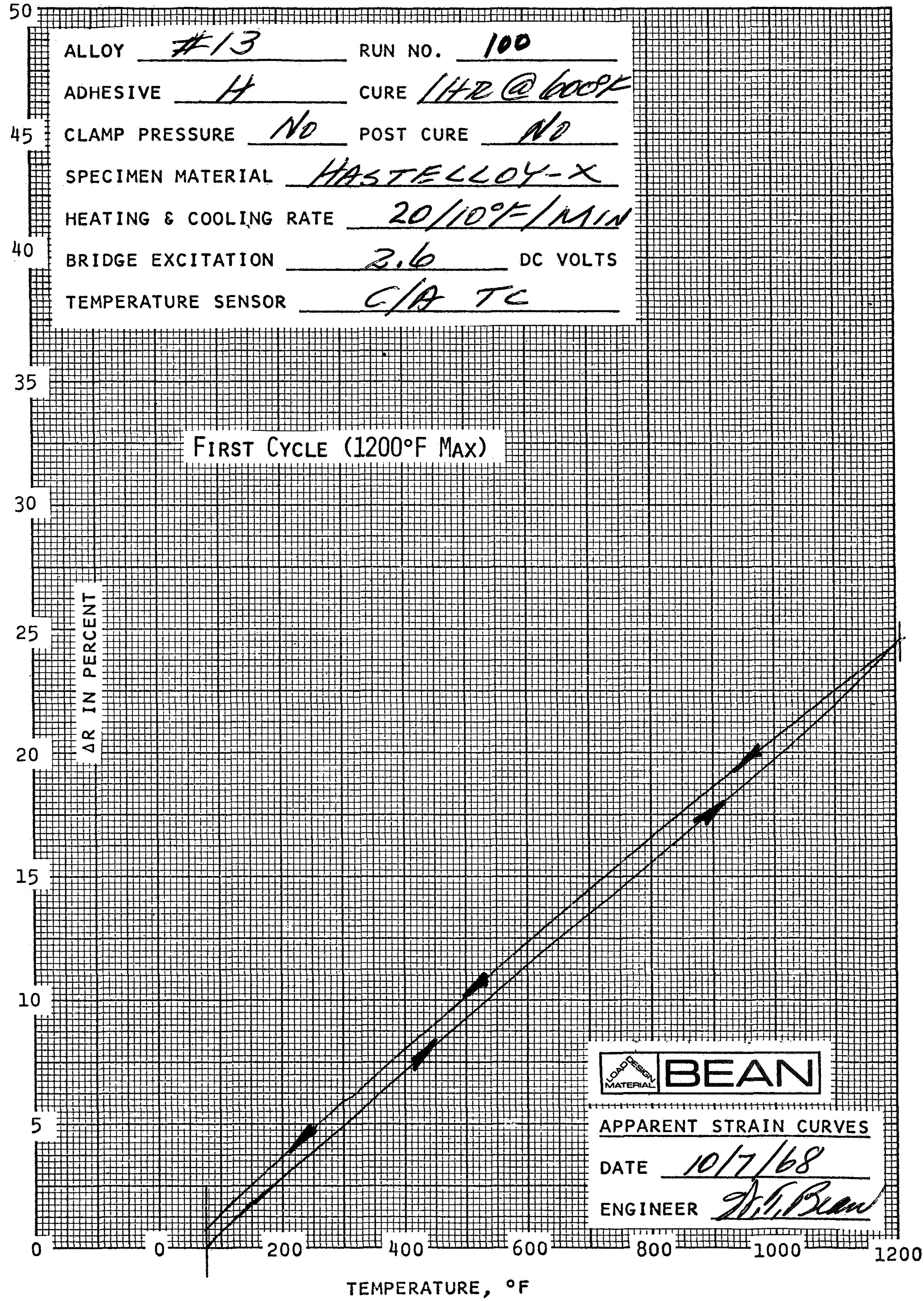
Alloy No.	Run No.
1	9, 10
2	13, 14, 15
5	24, 60
6	84, 85
7	88, 89
8	91, 92
9	94, 95
10	97
11	102, 104
14	107
15	109


ALLOY #3
RUN NO. 17
ADHESIVE H
CURE 1HR@600°F
CLAMP PRESSURE No
POST CURE No
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST CYCLE (1200°F MAX)
ΔR IN PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
TEMPERATURE. °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 1/27/68
ENGINEER

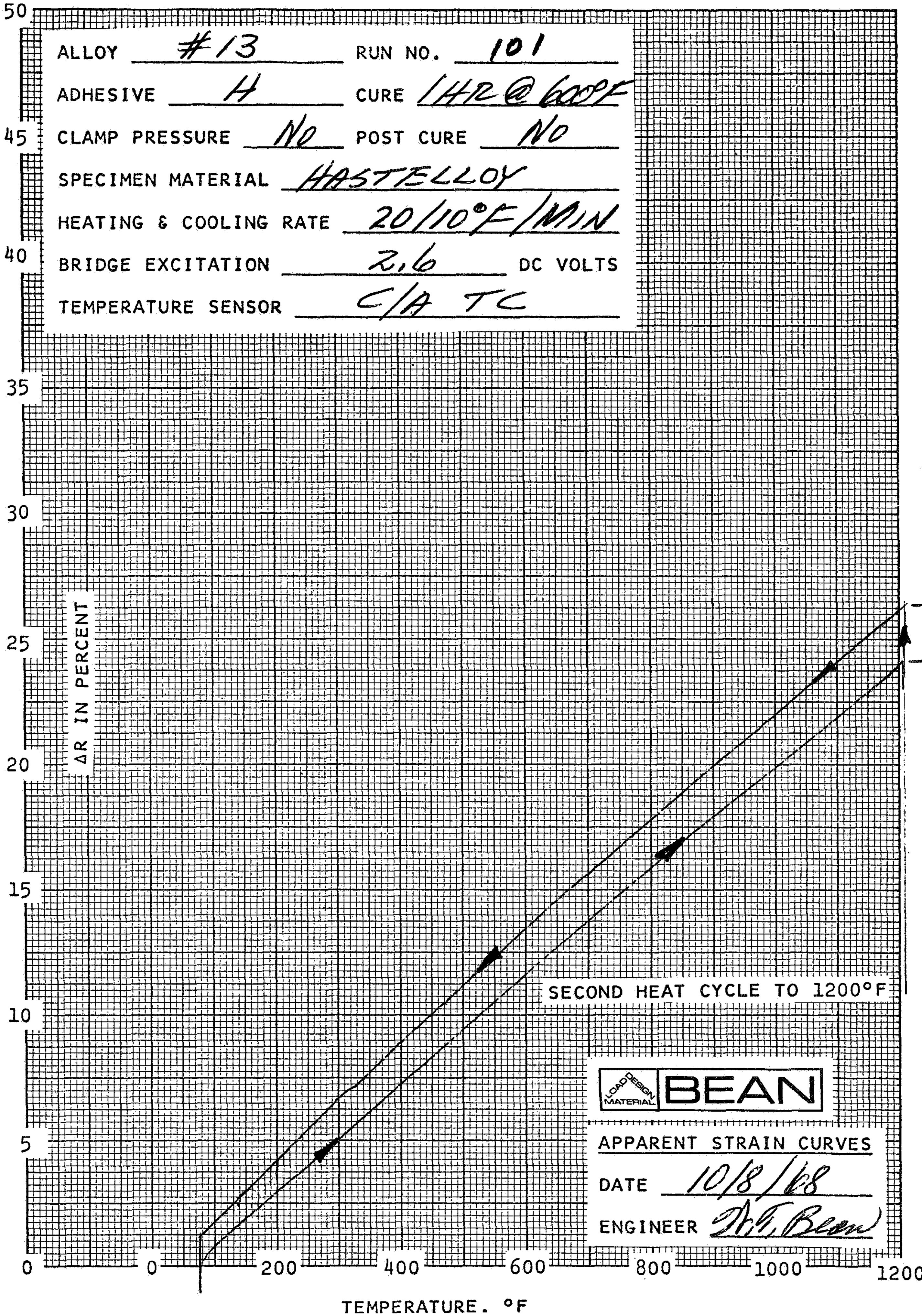

ALLOY #3
RUN NO. 18
ADHESIVE H
CURE 1HR@600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND CYCLE (1200°F MAX)
ΔR IN PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 1/28/68
ENGINEER W. T. Bean

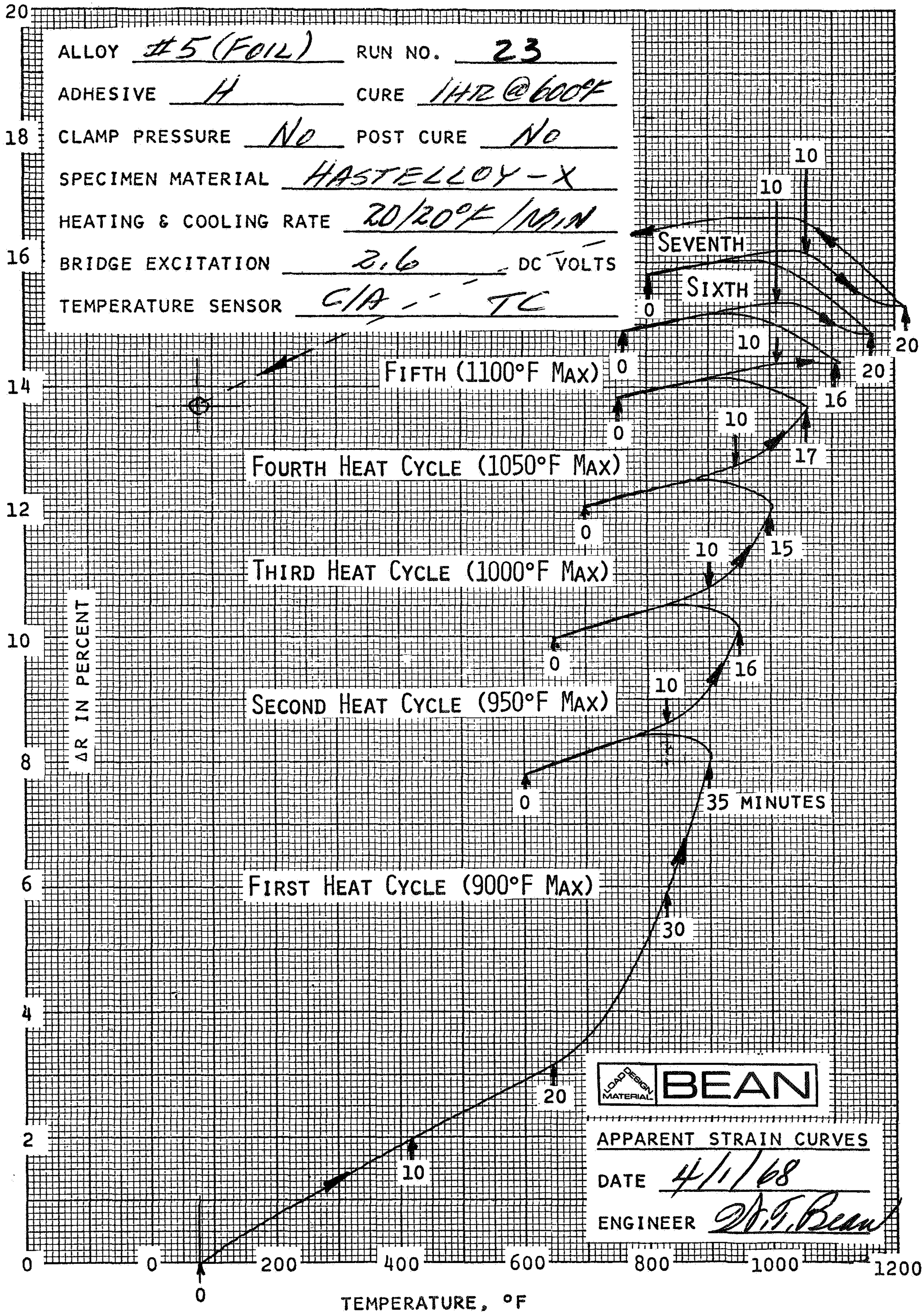

ALLOY #4
RUN NO. 20
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE No
POST CURE No
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST CYCLE (1200°F MAX)
ΔR IN PERCENT
TEMPERATURE, °F
0
5
10
15
20
25
30
35
40
45
50
200
400
600
800
1000
1200
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 3/1/68
ENGINEER W.T. Bean


ALLOY #4
RUN NO. 21
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND CYCLE (1200°F MAX)
ΔR IN PERCENT
0
5
10
15
20
25
30
35
40
45
50
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 3/2/68
ENGINEER W.T. Bean



ALLOY #13
RUN NO. 100
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST CYCLE (1200°F MAX)
ΔR IN PERCENT
0
5
10
15
20
25
30
35
40
45
50
0
200
400
600
800
1000
1200
TEMPERATURE, °F
BEAN
LOAD DESIGN MATERIAL
APPARENT STRAIN CURVES
DATE 10/7/68
ENGINEER D.T. Bean


ALLOY #13
RUN NO. 101
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
ΔR IN PERCENT
50
45
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
TEMPERATURE. °F
1 HR @ 1400°F
SECOND HEAT CYCLE TO 1200°F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 10/8/68
ENGINEER D. T. Bean


ALLOY #5 (FOIL)
RUN NO. 23
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SEVENTH
SIXTH
FIFTH (1100°F MAX)
FOURTH HEAT CYCLE (1050°F MAX)
THIRD HEAT CYCLE (1000°F MAX)
SECOND HEAT CYCLE (950°F MAX)
FIRST HEAT CYCLE (900°F MAX)
35 MINUTES
ΔR IN PERCENT
TEMPERATURE, °F
BEAN
LOAD DESIGN MATERIAL
APPARENT STRAIN CURVES
DATE 4/1/68
ENGINEER D.T. Bean

ALLOY #5 RUN NO. 27

ADHESIVE H CURE 1HR @ 600°F

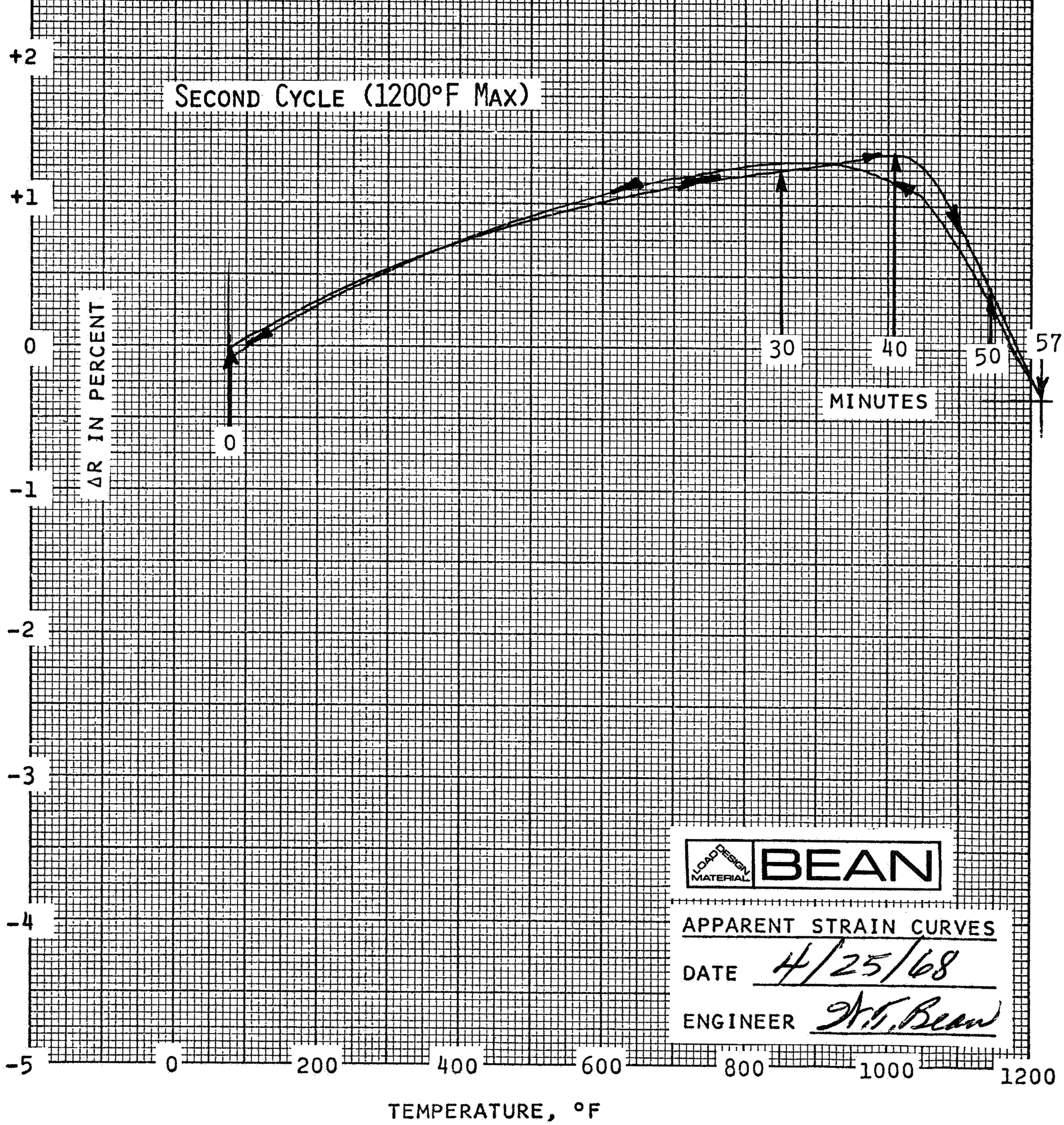
CLAMP PRESSURE No POST CURE No

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/10°F/MIN

BRIDGE EXCITATION 2.6 DC VOLTS

TEMPERATURE SENSOR C/A TC

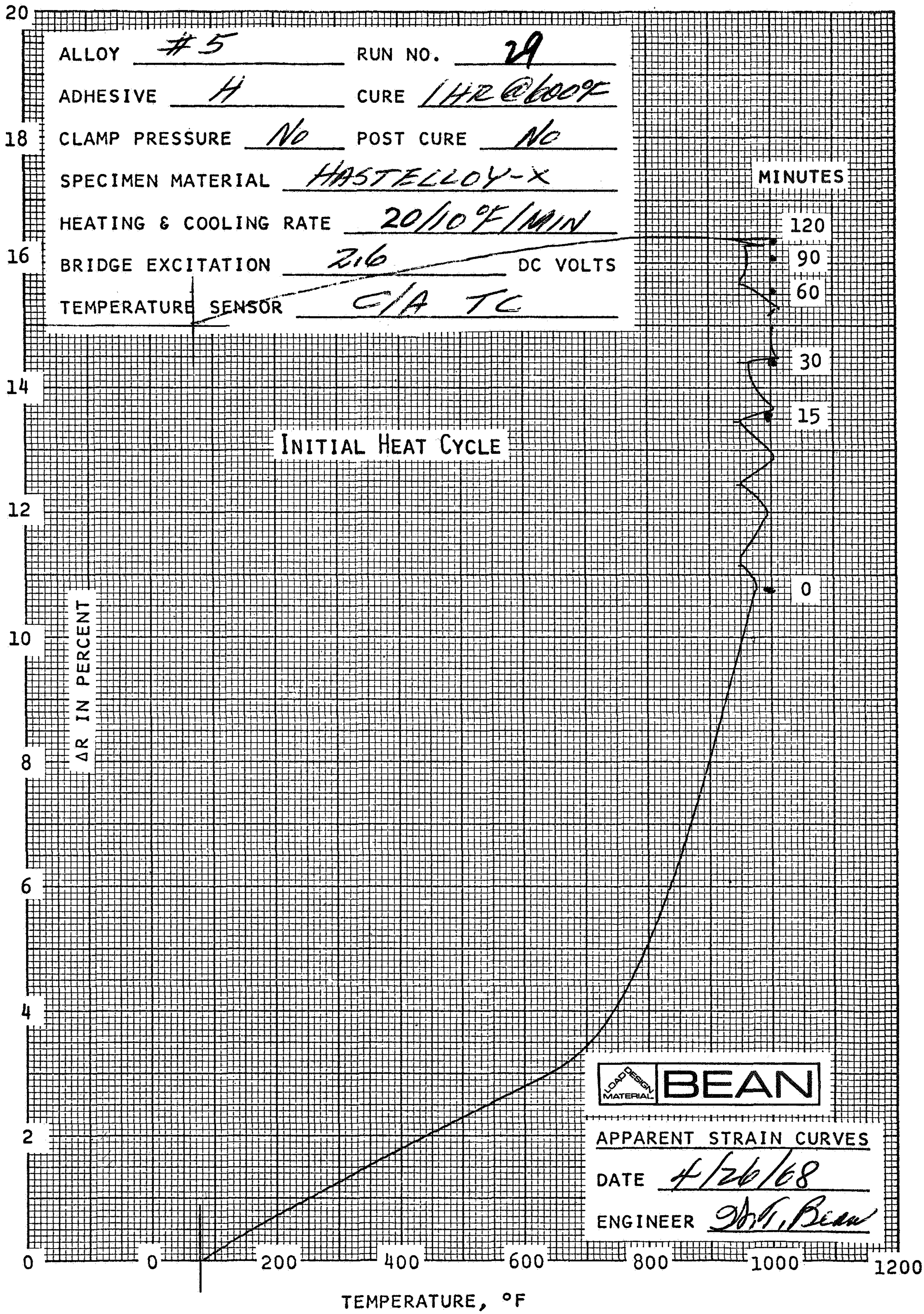


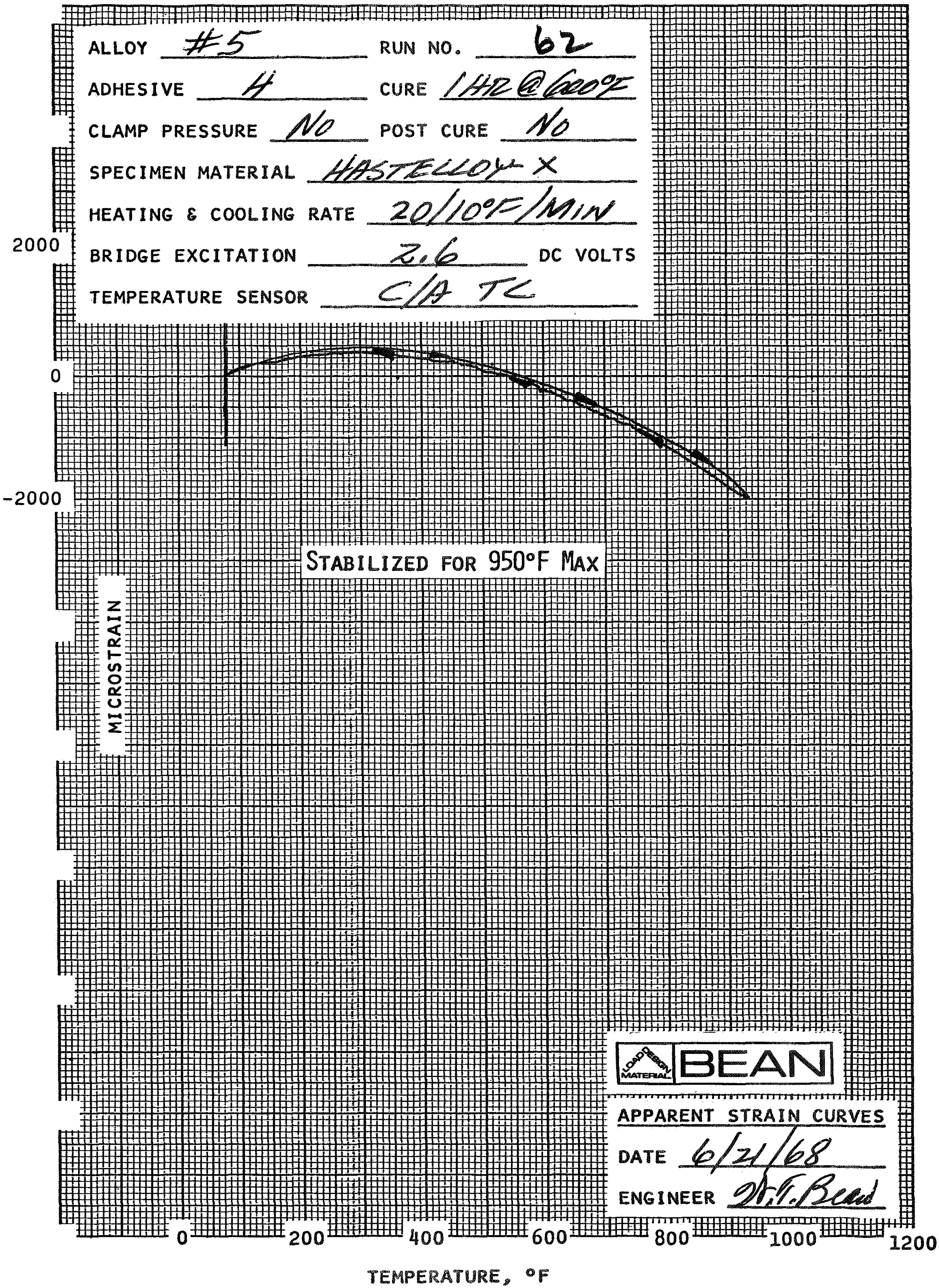
BEAN

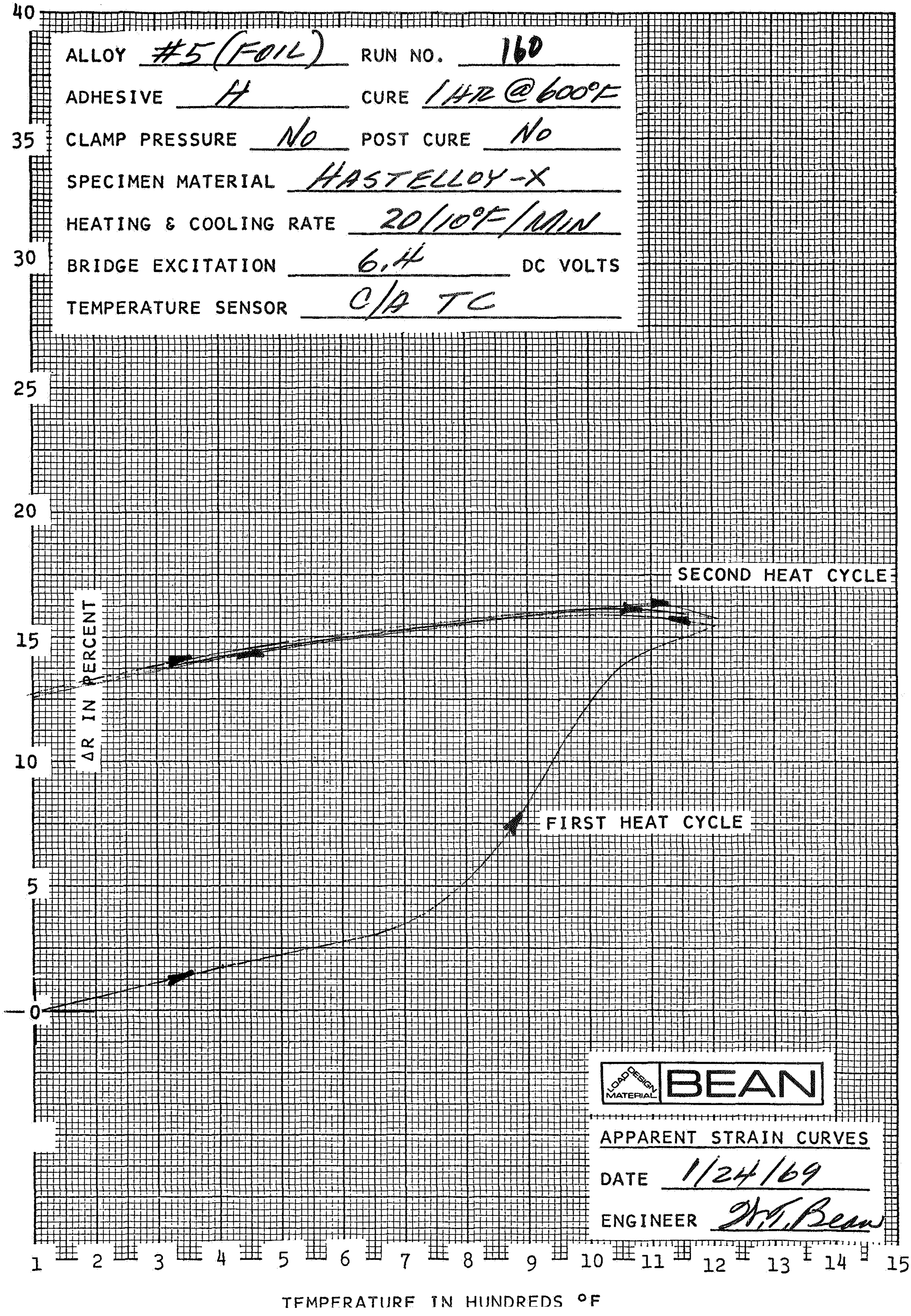
APPARENT STRAIN CURVES

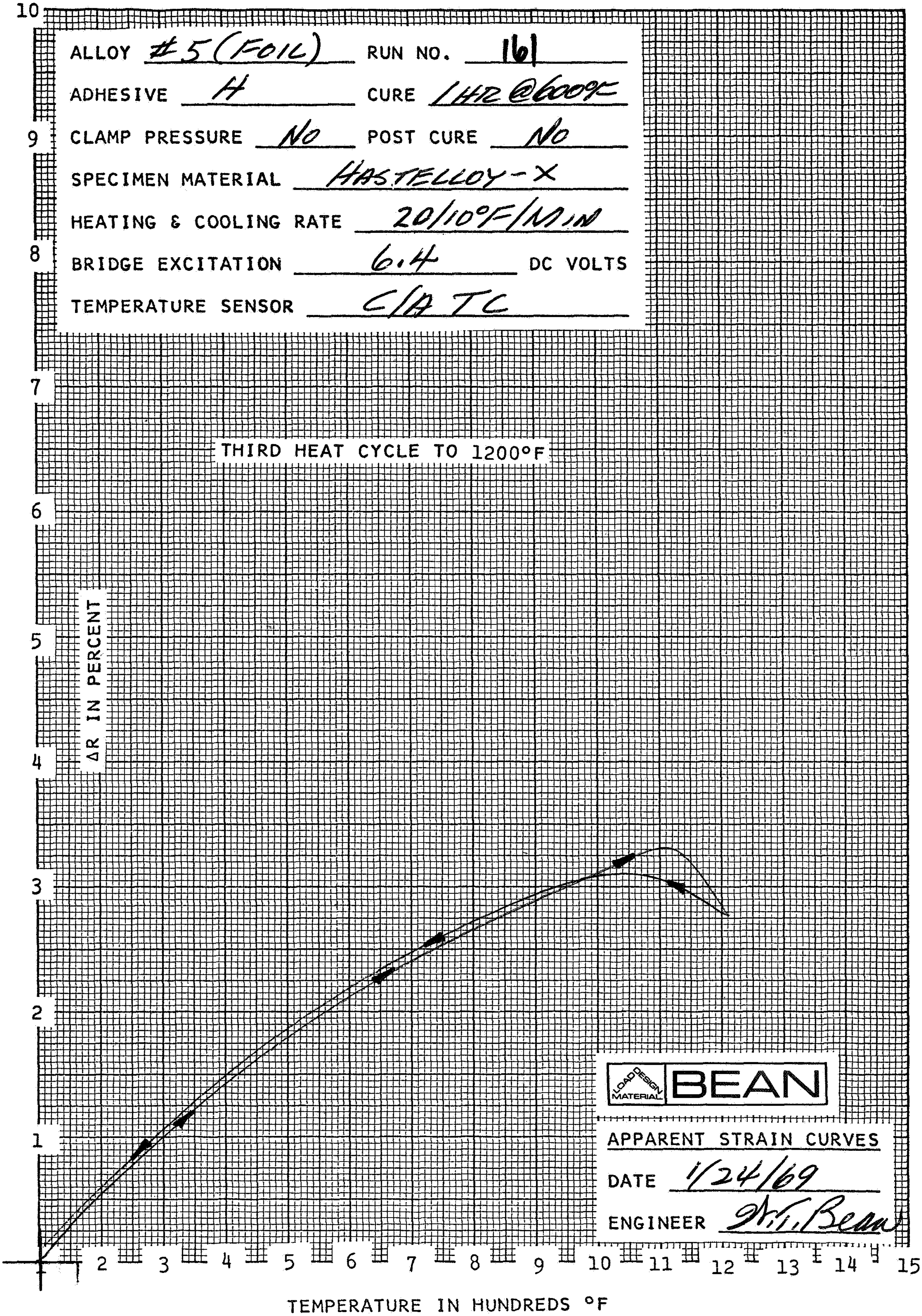
DATE 4/25/68

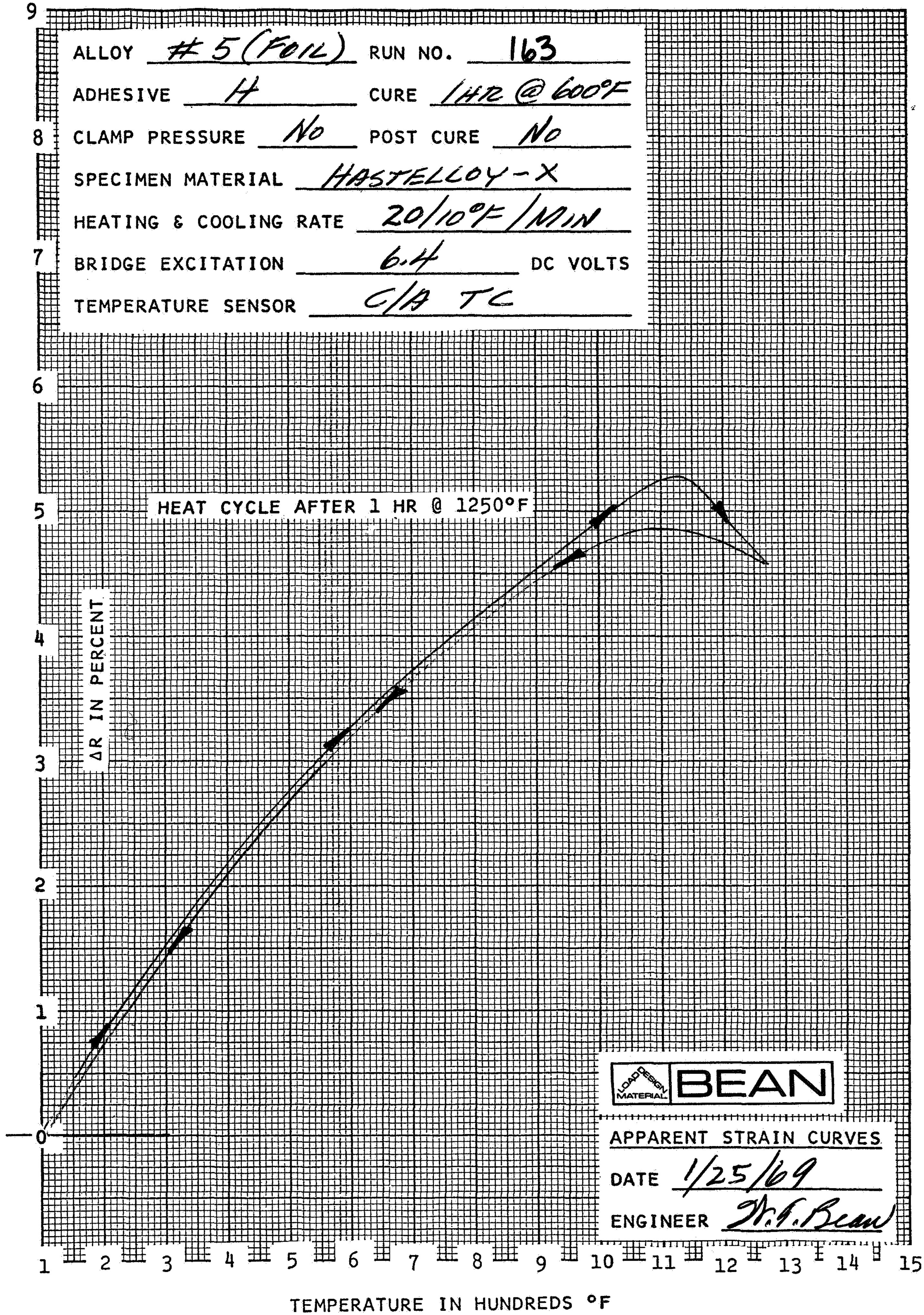
ENGINEER W.T. Bean

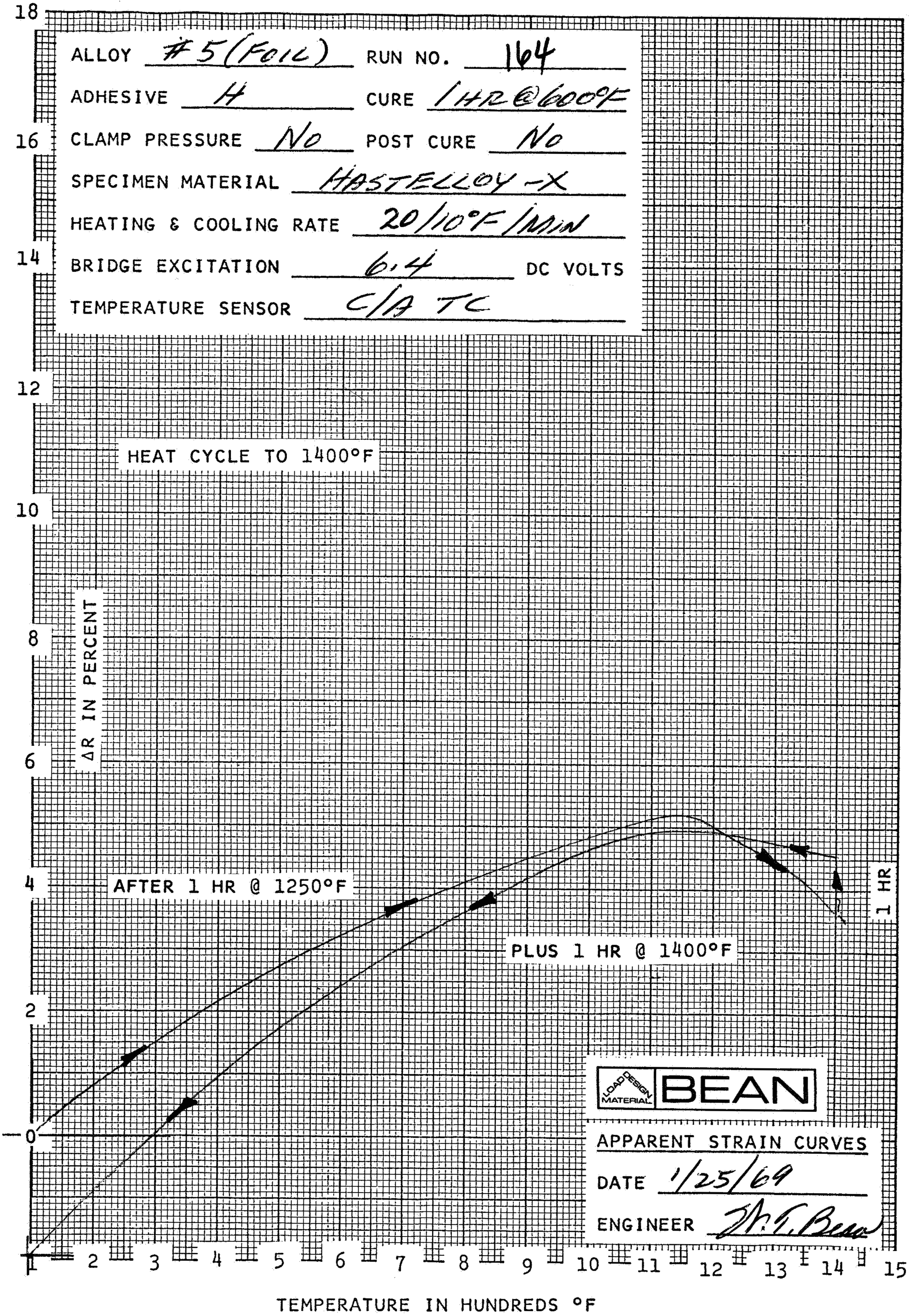

ALLOY #5
RUN NO. 29
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE No
POST CURE No
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
MINUTES
120
90
60
30
15
0
INITIAL HEAT CYCLE
ΔR IN PERCENT
0
2
4
6
8
10
12
14
16
18
20
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 4/26/68
ENGINEER W.T. Bean

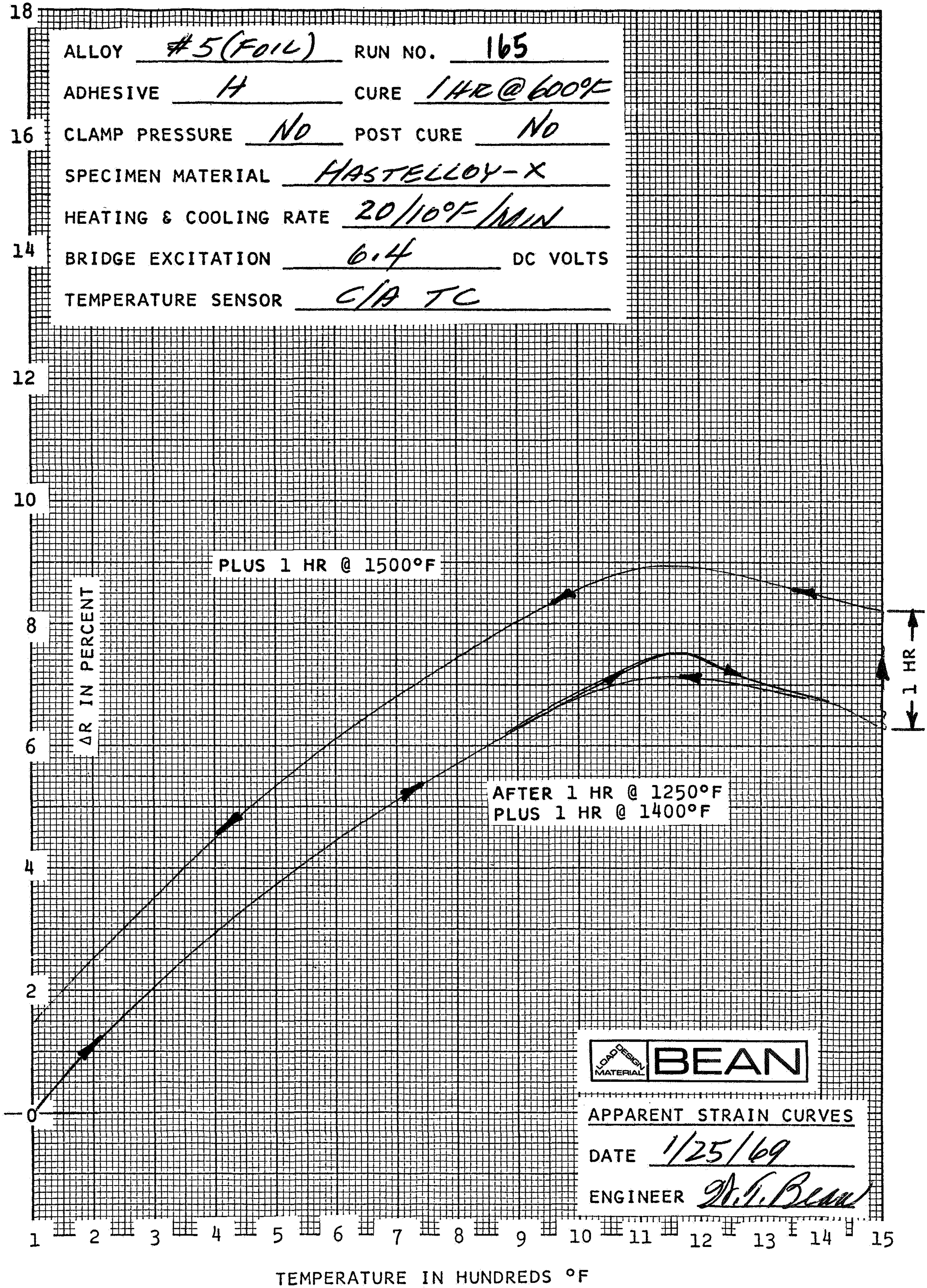

ALLOY #5
RUN NO. 62
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
2000
0
-2000
MICROSTRAIN
STABILIZED FOR 950°F MAX
0
200
400
600
800
1000
1200
TEMPERATURE, °F
BEAN
APPARENT STRAIN CURVES
DATE 6/21/68
ENGINEER W.T. Bean

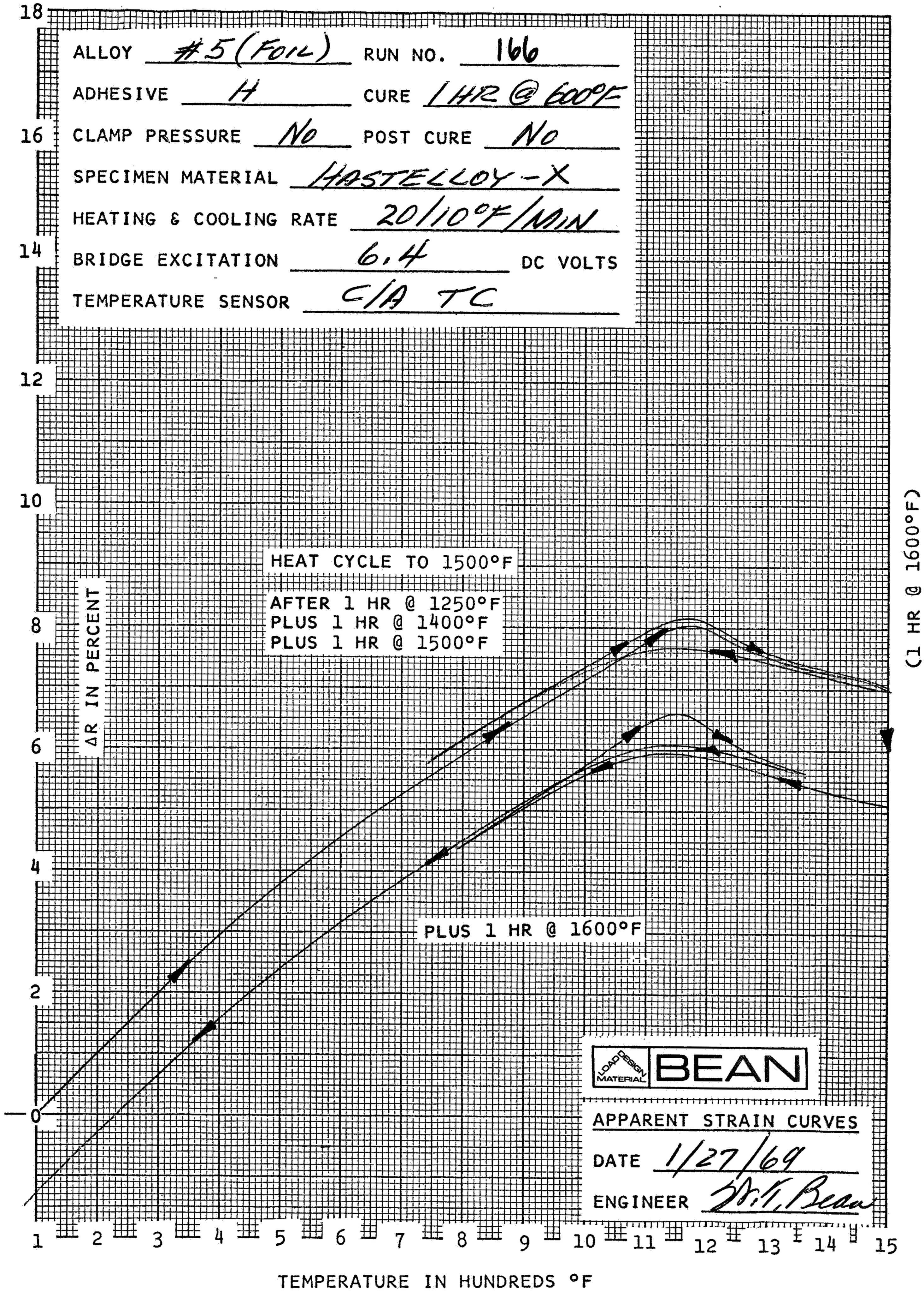

ALLOY #5 (FOIL)
RUN NO. 160
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND HEAT CYCLE
FIRST HEAT CYCLE
ΔR IN PERCENT
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 1/24/69
ENGINEER W. T. Bean

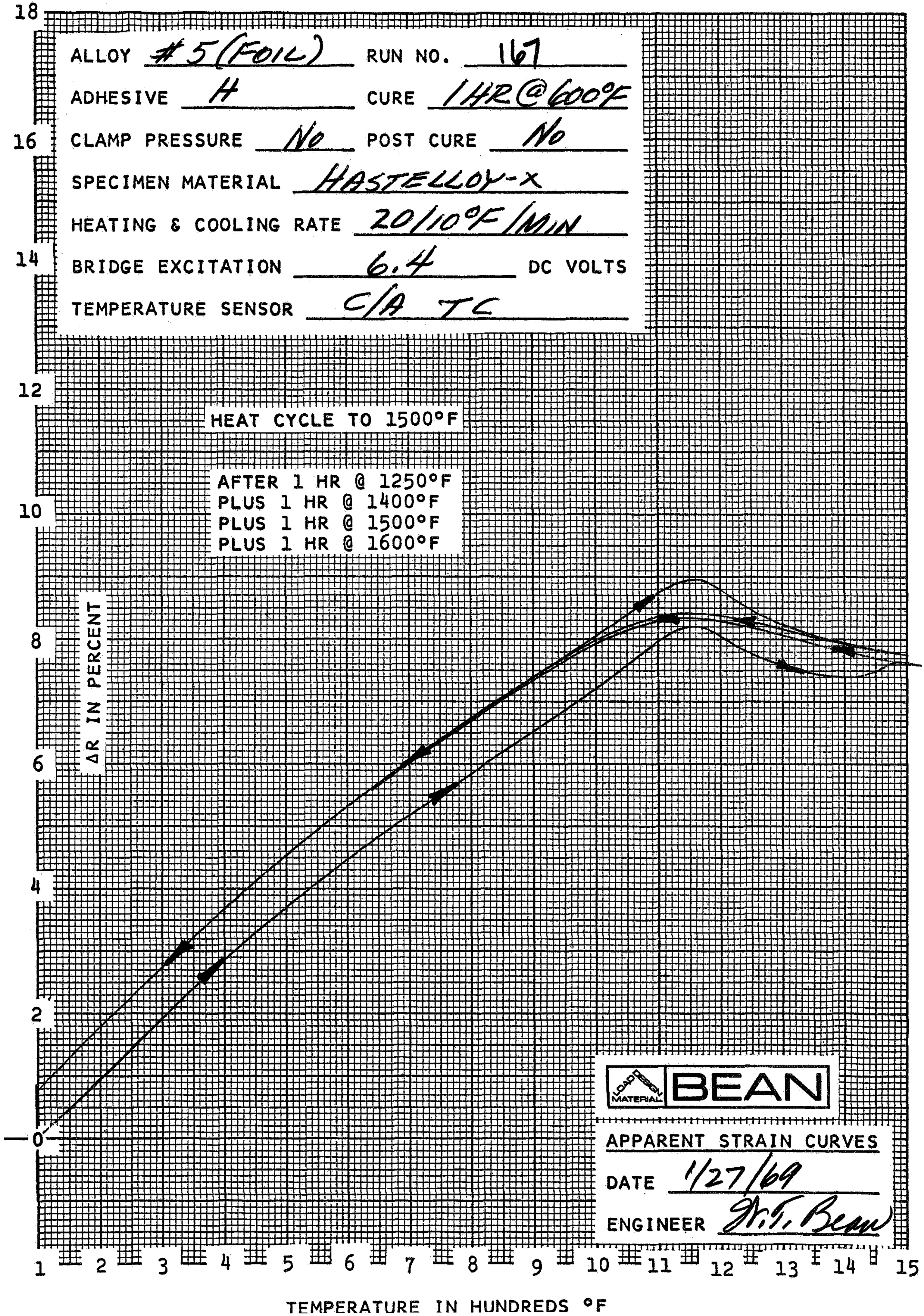

ALLOY #5 (FOIL) RUN NO. 161
ADHESIVE H CURE 1 HR @ 600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
THIRD HEAT CYCLE TO 1200°F
ΔR IN PERCENT
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
BEAN
APPARENT STRAIN CURVES
DATE 1/24/69
ENGINEER W. T. Bean

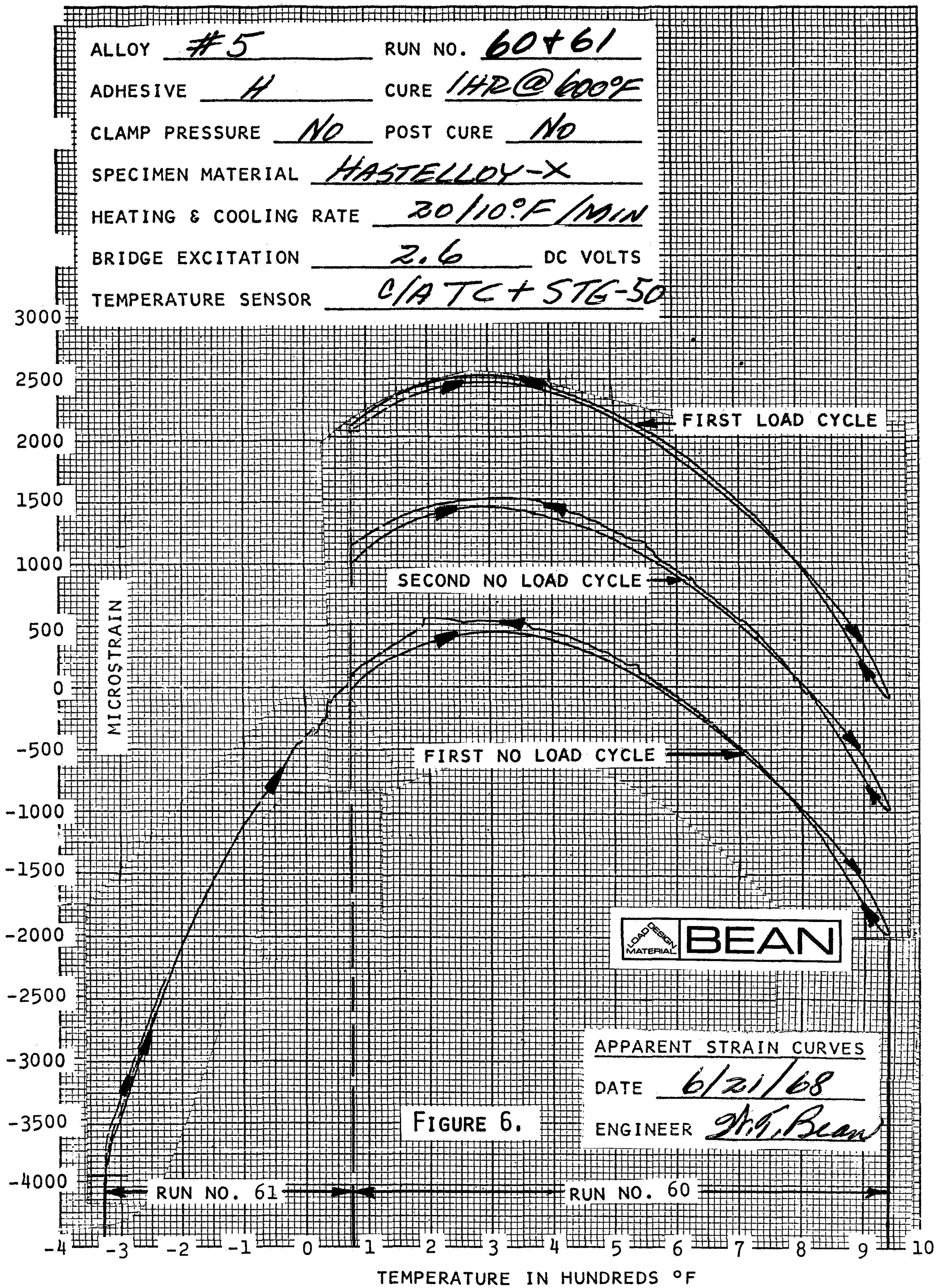

ALLOY #5 (FOIL) RUN NO. 163
ADHESIVE H CURE 1HR @ 600°F
CLAMP PRESSURE No POST CURE No
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
HEAT CYCLE AFTER 1 HR @ 1250°F
ΔR IN PERCENT
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 1/25/69
ENGINEER W.F. Bean


ALLOY #5 (FOIL)
RUN NO. 164
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
HEAT CYCLE TO 1400°F
AFTER 1 HR @ 1250°F
PLUS 1 HR @ 1400°F
1 HR
ΔR IN PERCENT
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 1/25/69
ENGINEER W. T. Bean
0
2
4
6
8
10
12
14
16
18
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15


ALLOY #5(FOIL) RUN NO. 165
ADHESIVE H CURE 1HR@600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
PLUS 1 HR @ 1500°F
AFTER 1 HR @ 1250°F
PLUS 1 HR @ 1400°F
1 HR
ΔR IN PERCENT
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 1/25/69
ENGINEER W.T. Bean

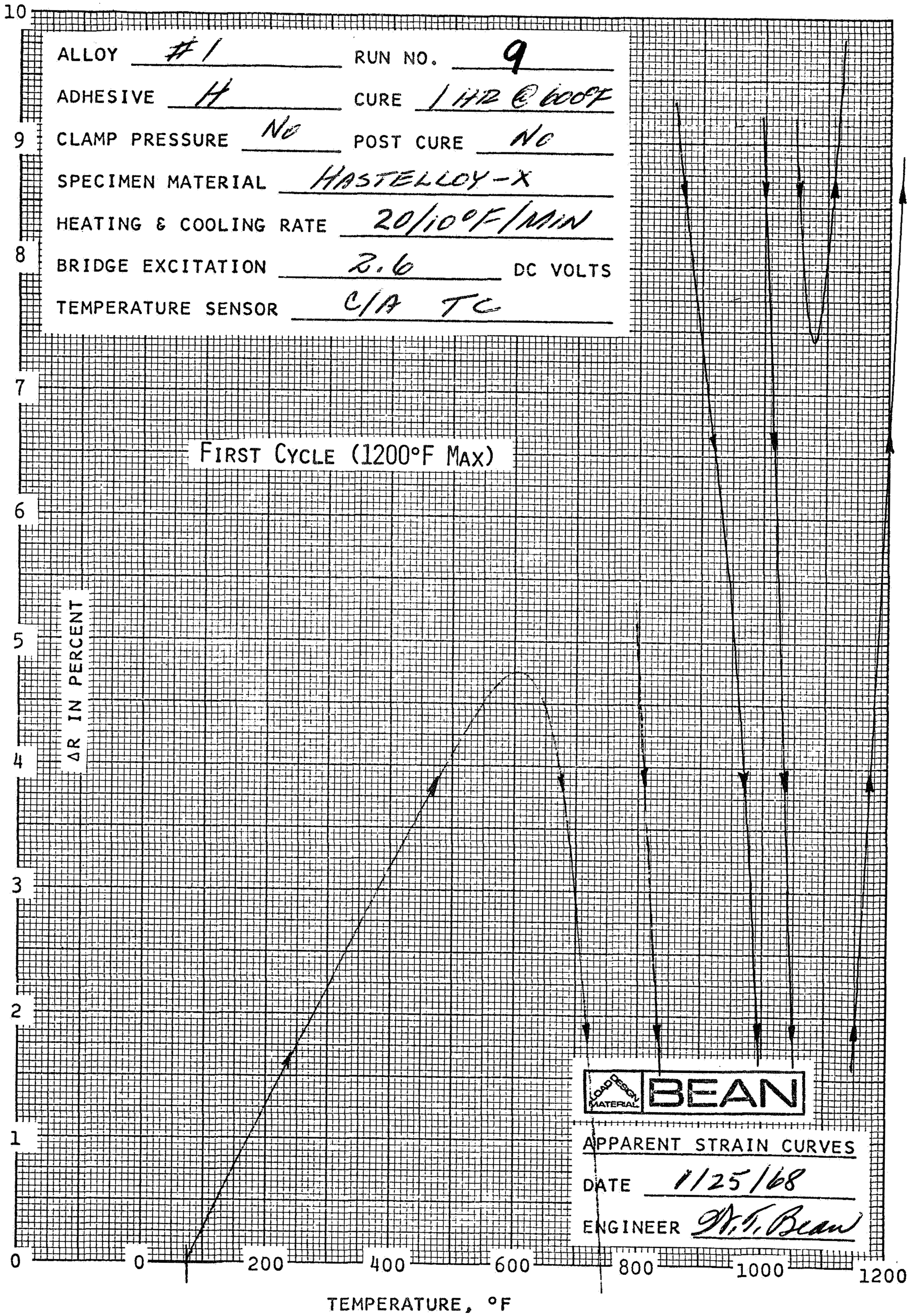

ALLOY #5 (FOIL)
RUN NO. 166
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
HEAT CYCLE TO 1500°F
AFTER 1 HR @ 1250°F
PLUS 1 HR @ 1400°F
PLUS 1 HR @ 1500°F
PLUS 1 HR @ 1600°F
(1 HR @ 1600°F)
ΔR IN PERCENT
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 1/27/69
ENGINEER

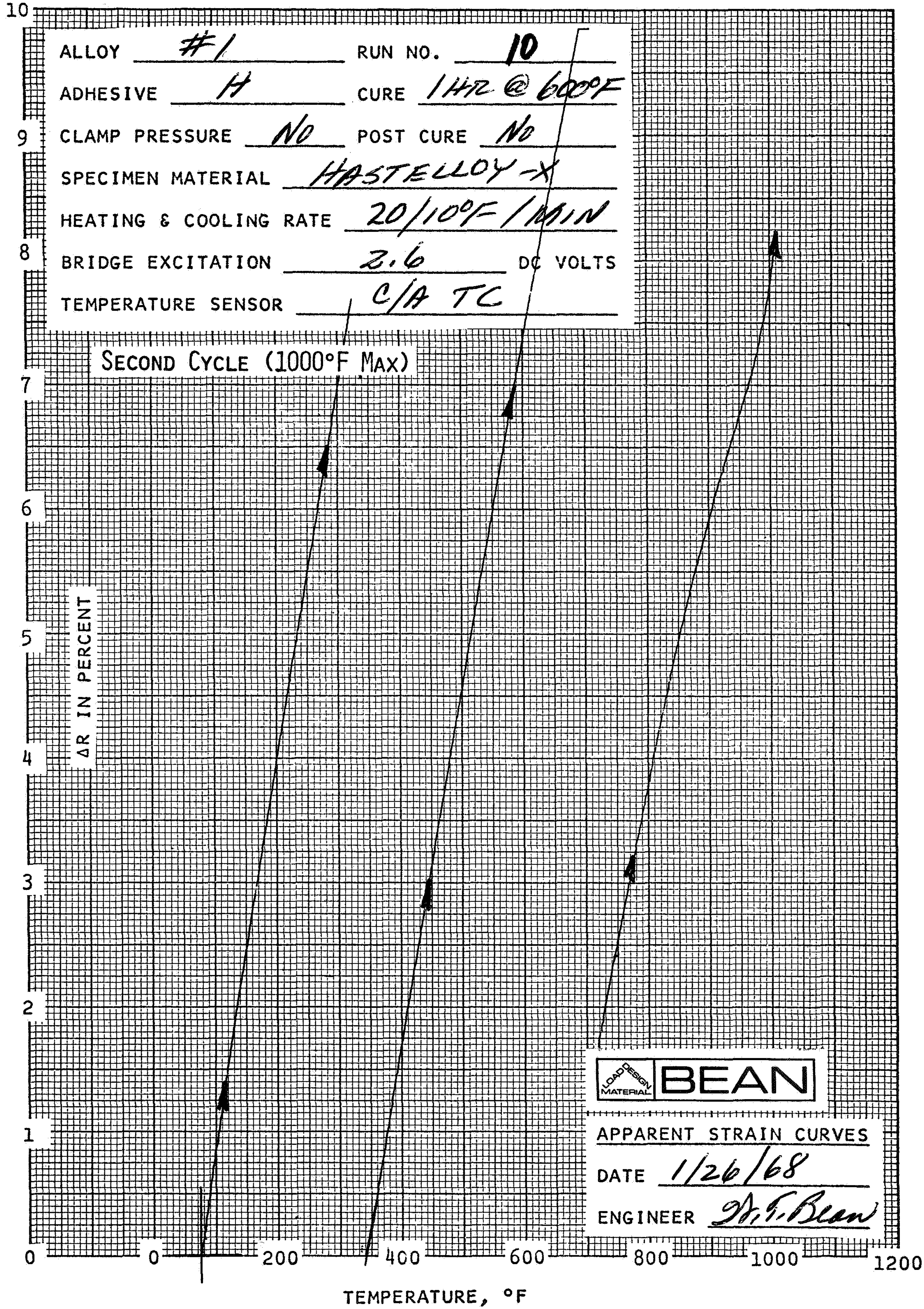

ALLOY #5 (FOIL)
RUN NO. 167
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE No
POST CURE No
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
HEAT CYCLE TO 1500°F
AFTER 1 HR @ 1250°F
PLUS 1 HR @ 1400°F
PLUS 1 HR @ 1500°F
PLUS 1 HR @ 1600°F
ΔR IN PERCENT
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 1/27/69
ENGINEER W.T. Bean



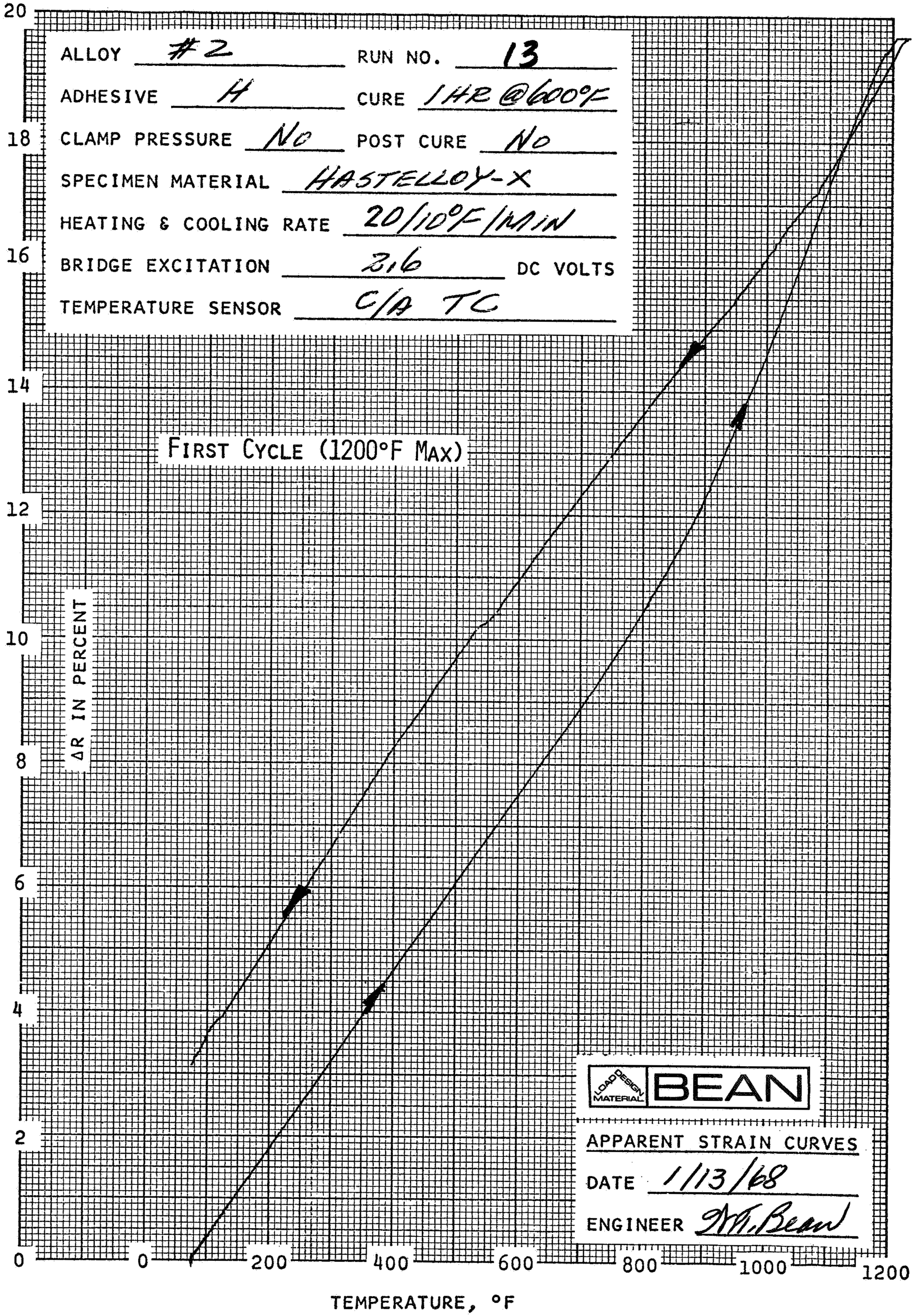
ALLOY #5
RUN NO. 60+61
ADHESIVE H
CURE 1HR@600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC+STG-50
FIRST LOAD CYCLE
SECOND NO LOAD CYCLE
FIRST NO LOAD CYCLE
MICROSTRAIN
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 6/21/68
ENGINEER W.T. Bean
RUN NO. 61
RUN NO. 60
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
TEMPERATURE IN HUNDREDS °F

FIGURE 6.

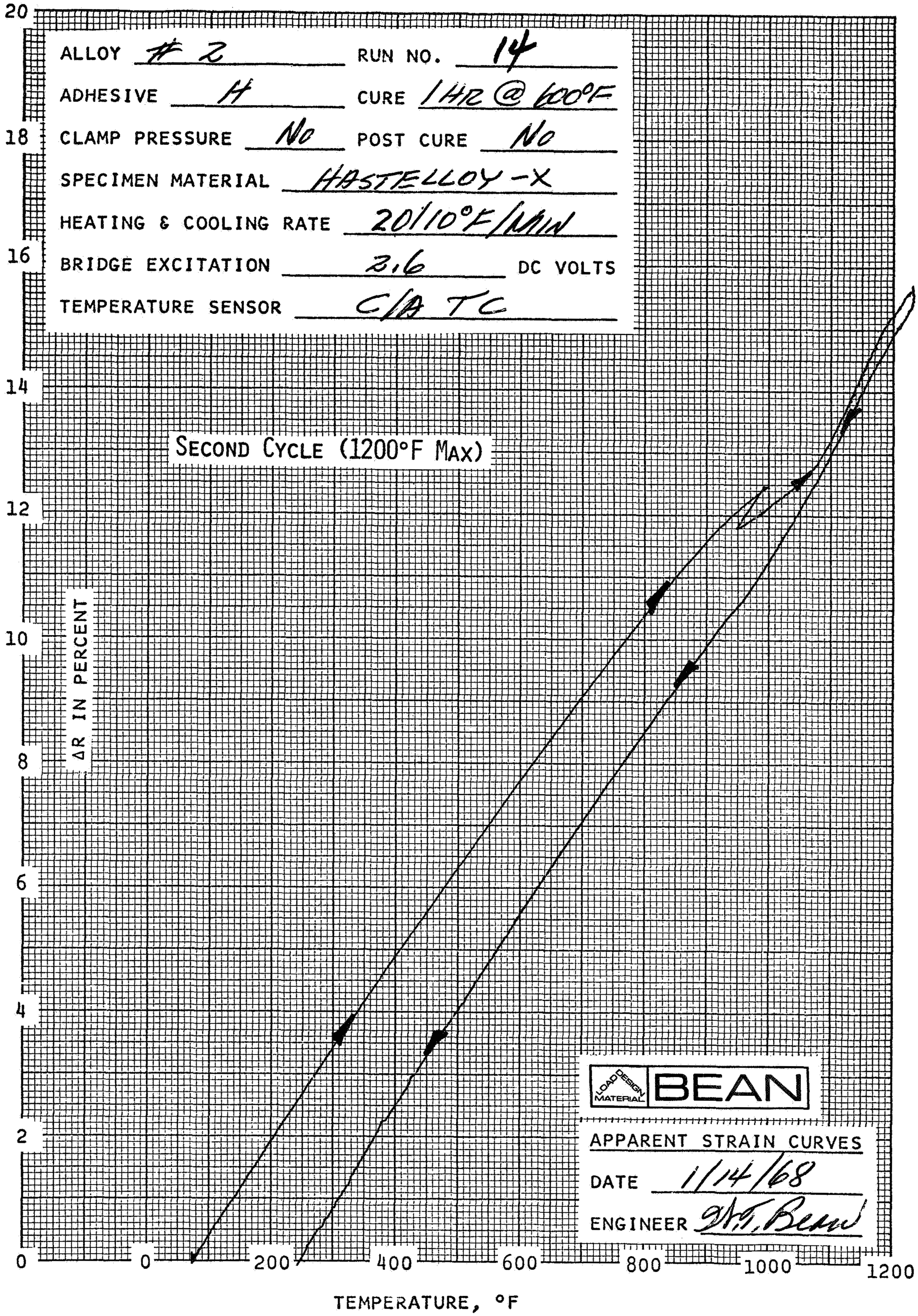

ALLOY #1
RUN NO. 9
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST CYCLE (1200°F MAX)
ΔR IN PERCENT
0
1
2
3
4
5
6
7
8
9
10
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 1/25/68
ENGINEER W. T. Bean

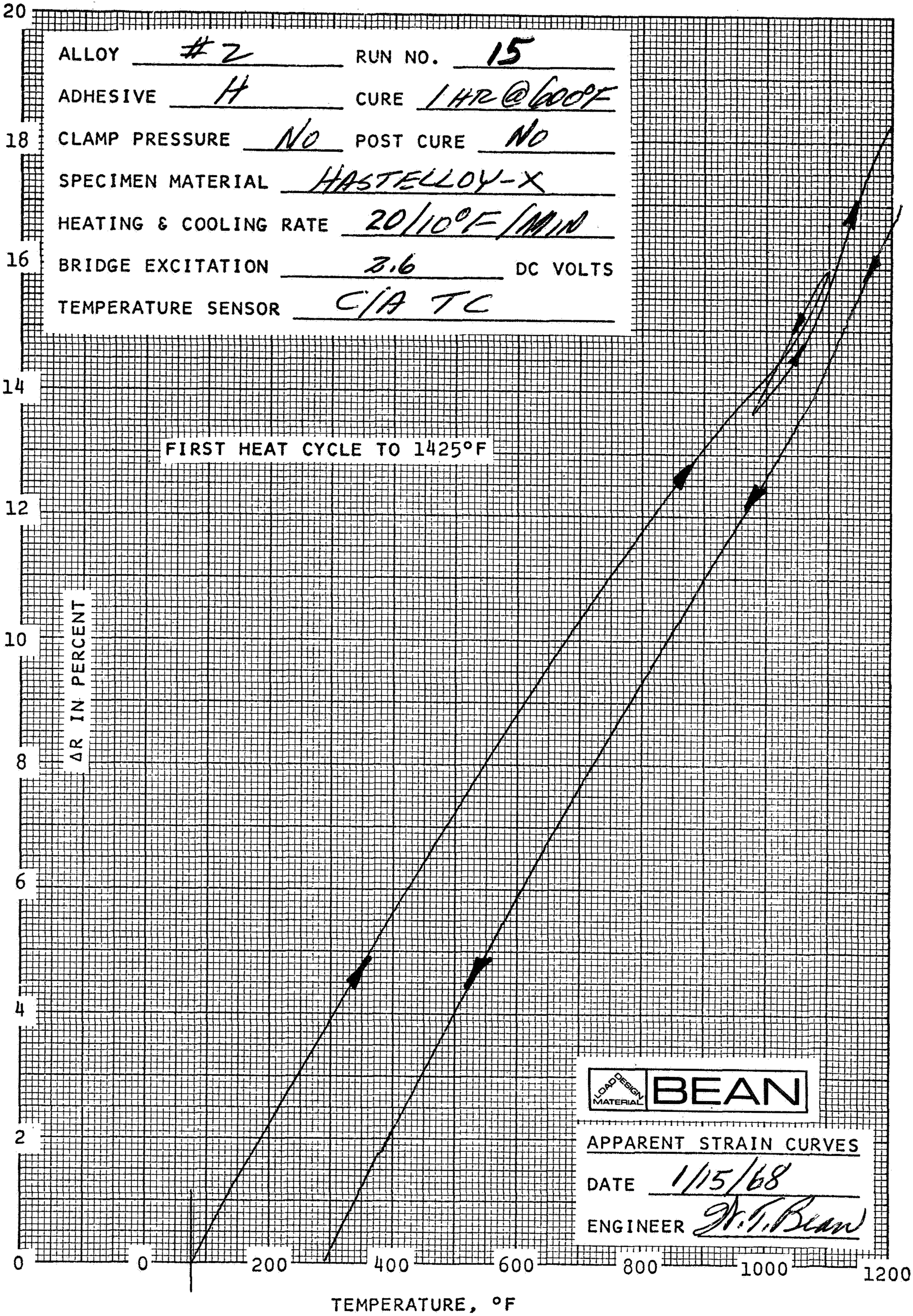


ALLOY #1
RUN NO. 10
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND CYCLE (1000°F MAX)
ΔR IN PERCENT
0
1
2
3
4
5
6
7
8
9
10
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 1/26/68
ENGINEER D. F. Bean

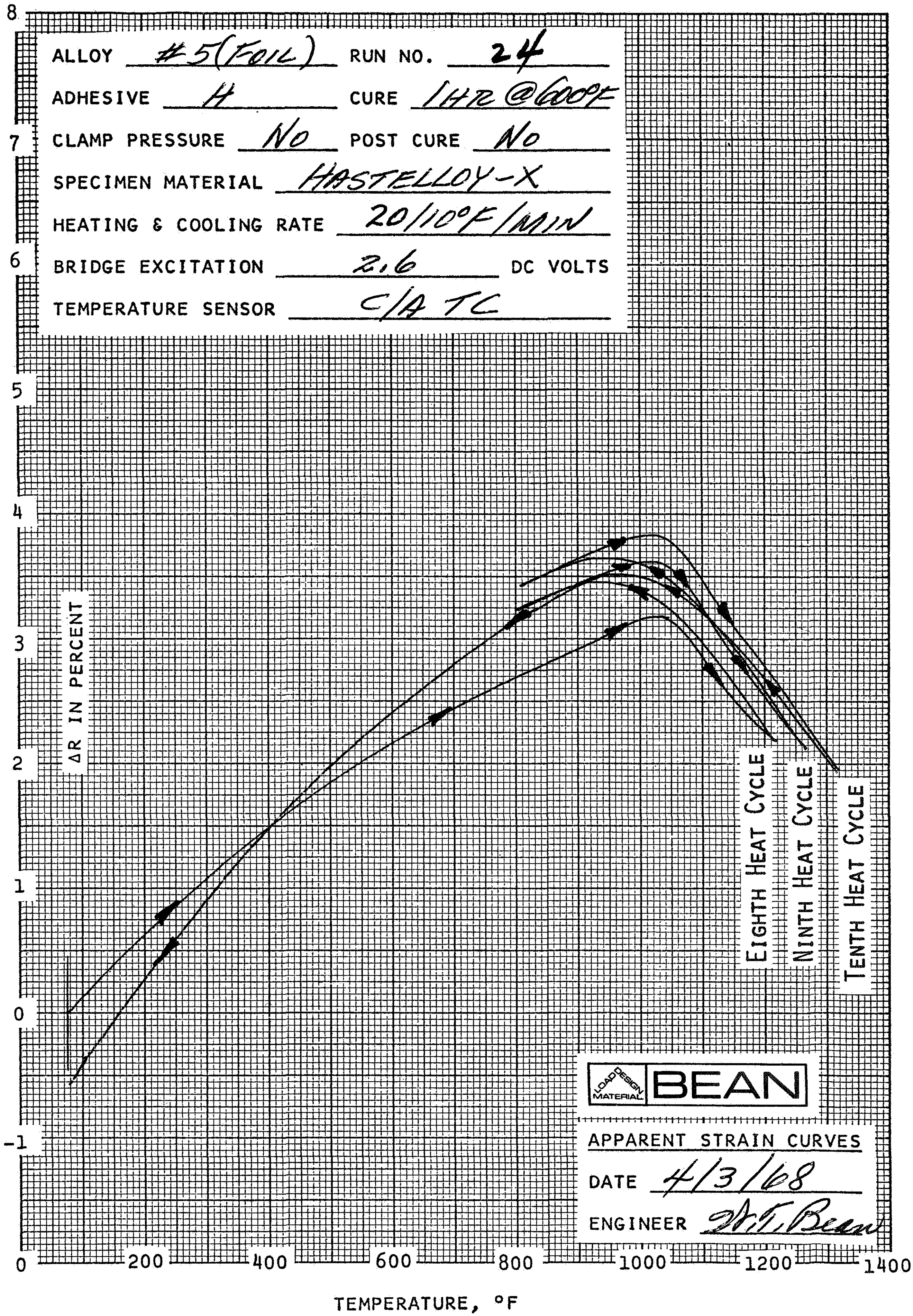


ALLOY #2
RUN NO. 13
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE No
POST CURE No
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 3.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST CYCLE (1200°F MAX)
ΔR IN PERCENT
0
2
4
6
8
10
12
14
16
18
20
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 1/13/68
ENGINEER W. Bean

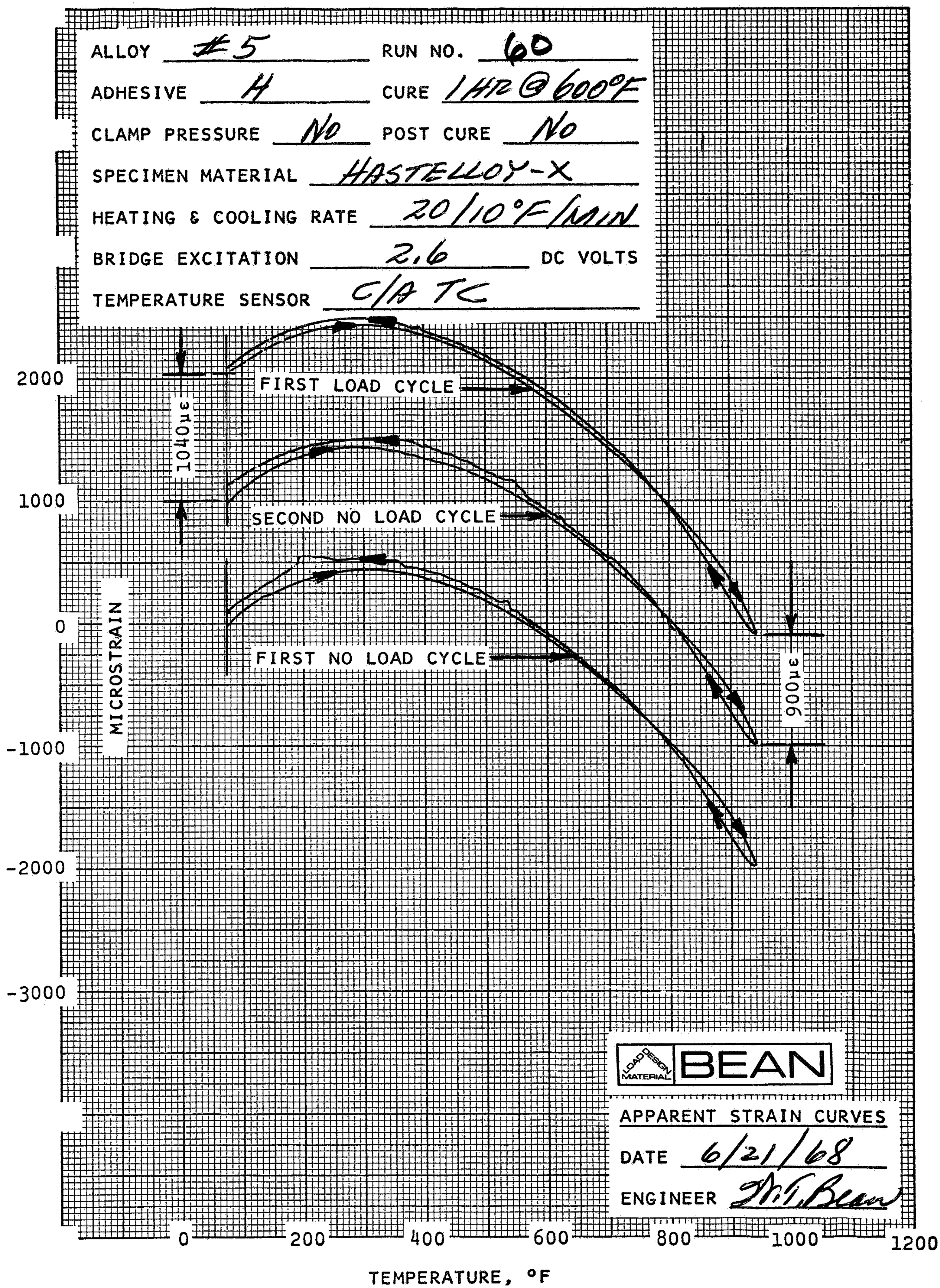

ALLOY # 2
RUN NO. 14
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE No
POST CURE No
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 3.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND CYCLE (1200°F MAX)
ΔR IN PERCENT
0
2
4
6
8
10
12
14
16
18
20
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 1/14/68
ENGINEER D.T. Bean

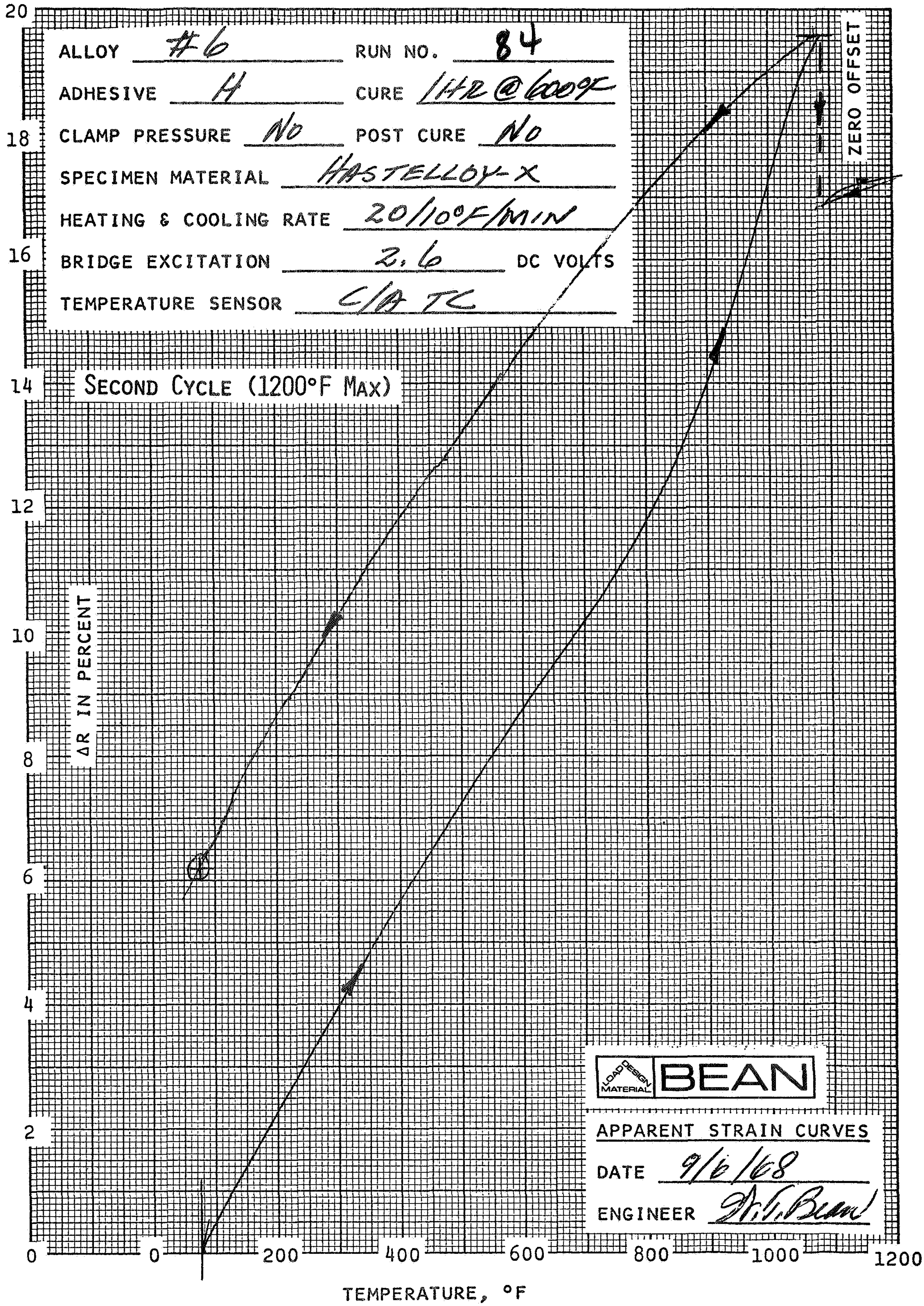


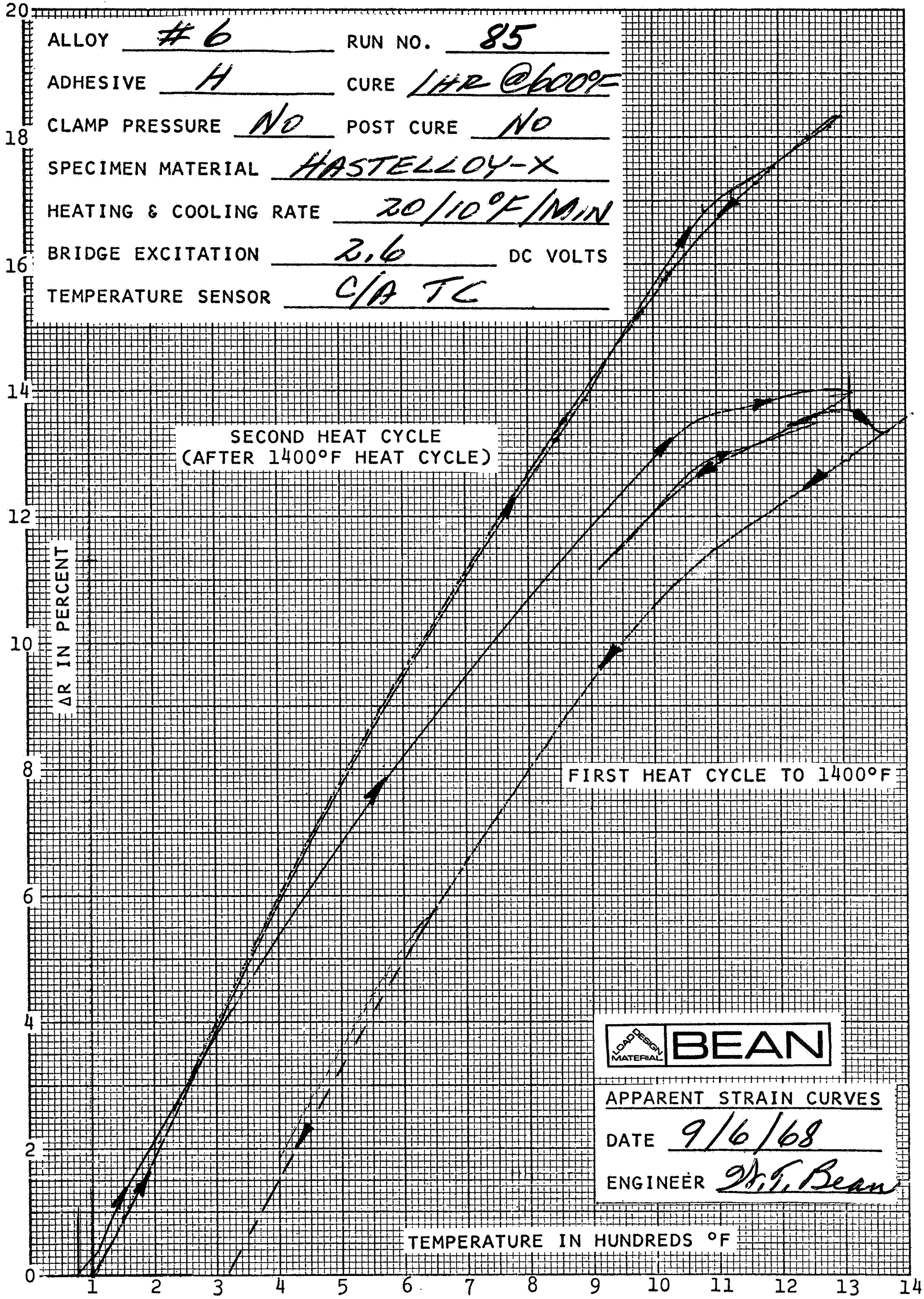
ALLOY #2
RUN NO. 15
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 3.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST HEAT CYCLE TO 1425°F
ΔR IN PERCENT
0
2
4
6
8
10
12
14
16
18
20
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 1/15/68
ENGINEER W. T. Bean

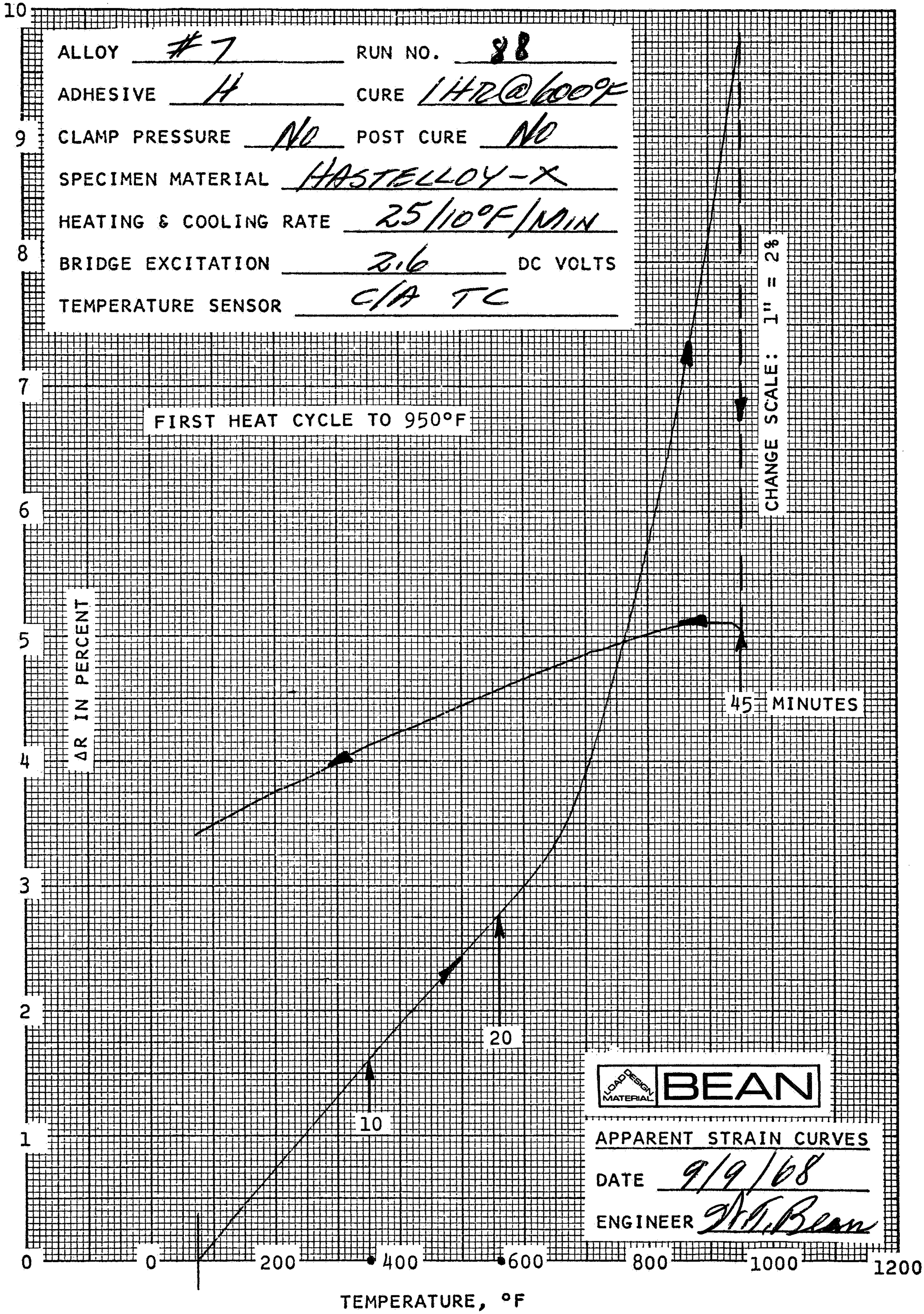


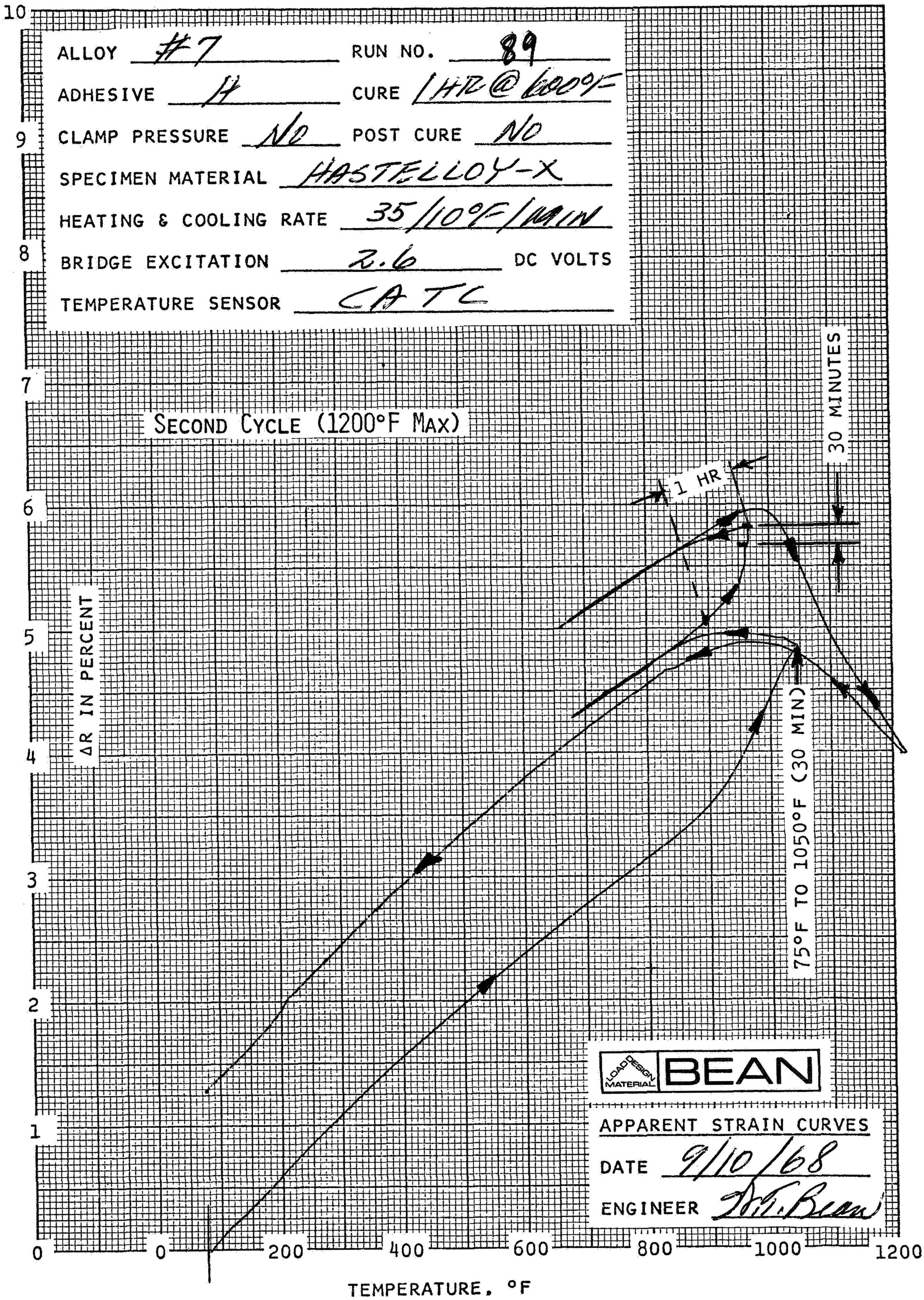
ALLOY #5(FOIL) RUN NO. 24
ADHESIVE H CURE 1HR @600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
ΔR IN PERCENT
8
7
6
5
4
3
2
1
0
-1
0
200
400
600
800
1000
1200
1400
TEMPERATURE, °F
EIGHTH HEAT CYCLE
NINTH HEAT CYCLE
TENTH HEAT CYCLE
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 4/3/68
ENGINEER W.T. Bean

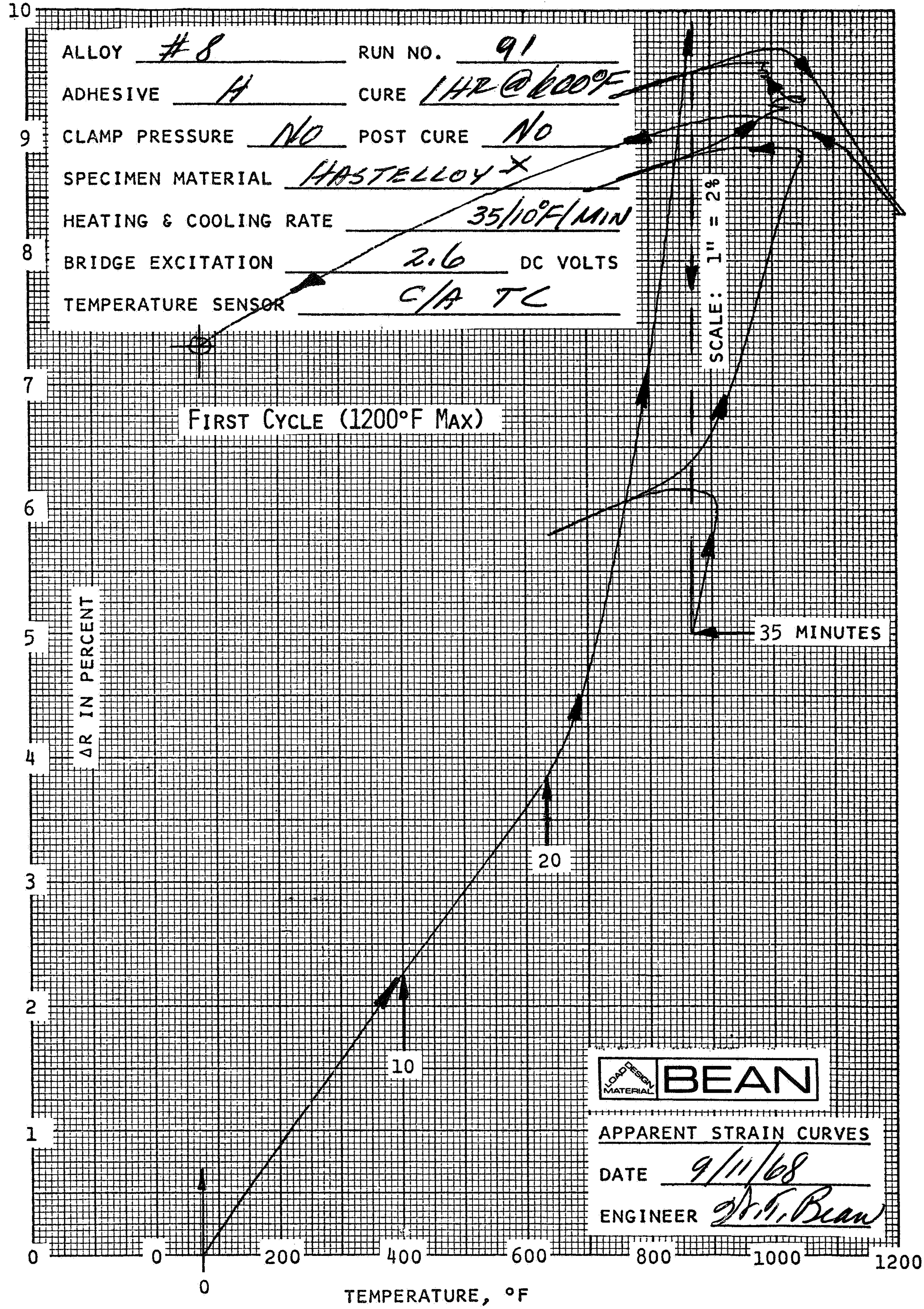

ALLOY #5
RUN NO. 60
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST LOAD CYCLE
SECOND NO LOAD CYCLE
FIRST NO LOAD CYCLE
1040με
900με
MICROSTRAIN
2000
1000
0
-1000
-2000
-3000
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 6/21/68
ENGINEER D.T. Bean

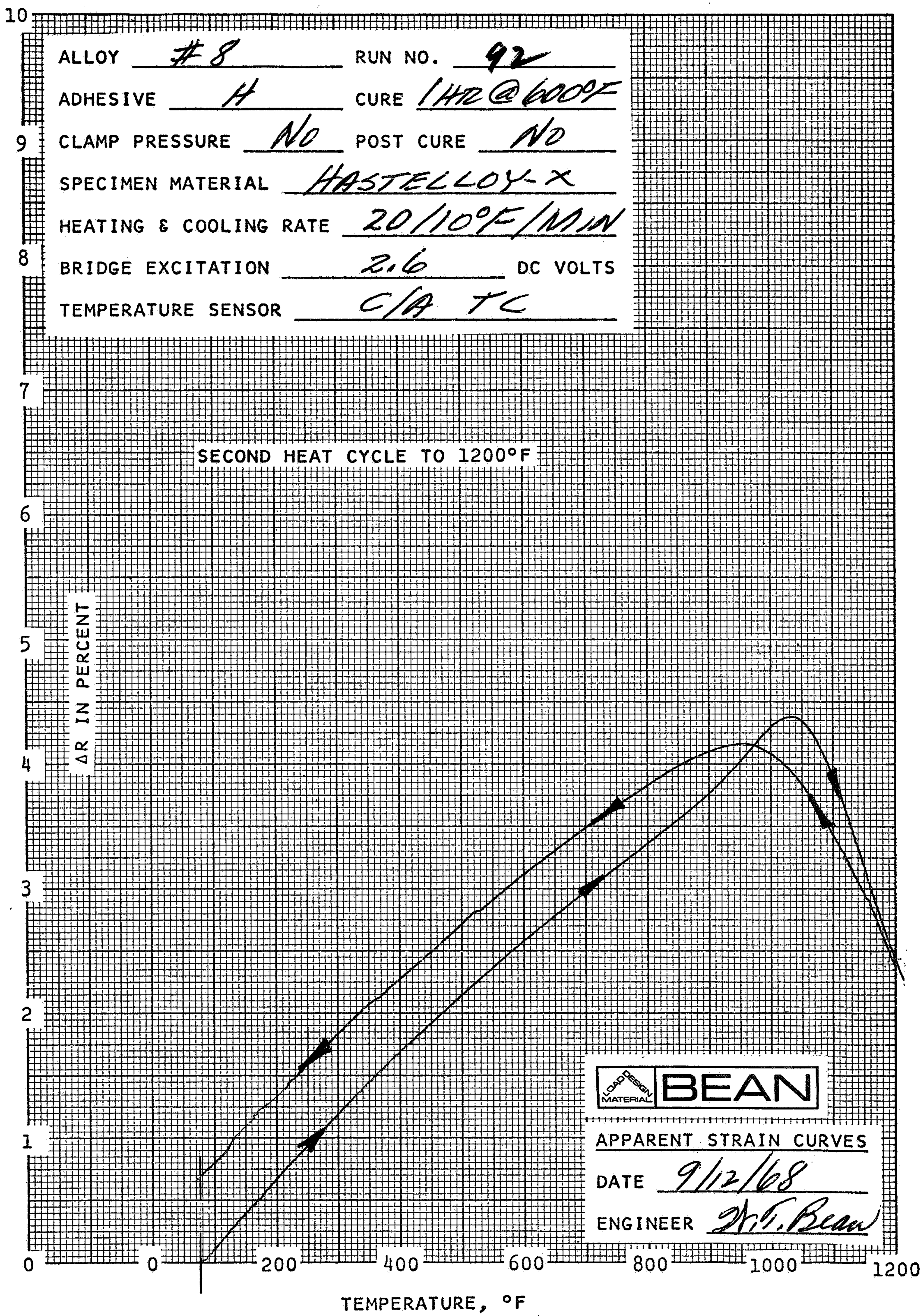

ALLOY #6
RUN NO. 84
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND CYCLE (1200°F MAX)
ZERO OFFSET
ΔR IN PERCENT
20
18
16
14
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 9/6/68
ENGINEER D.T. Bean

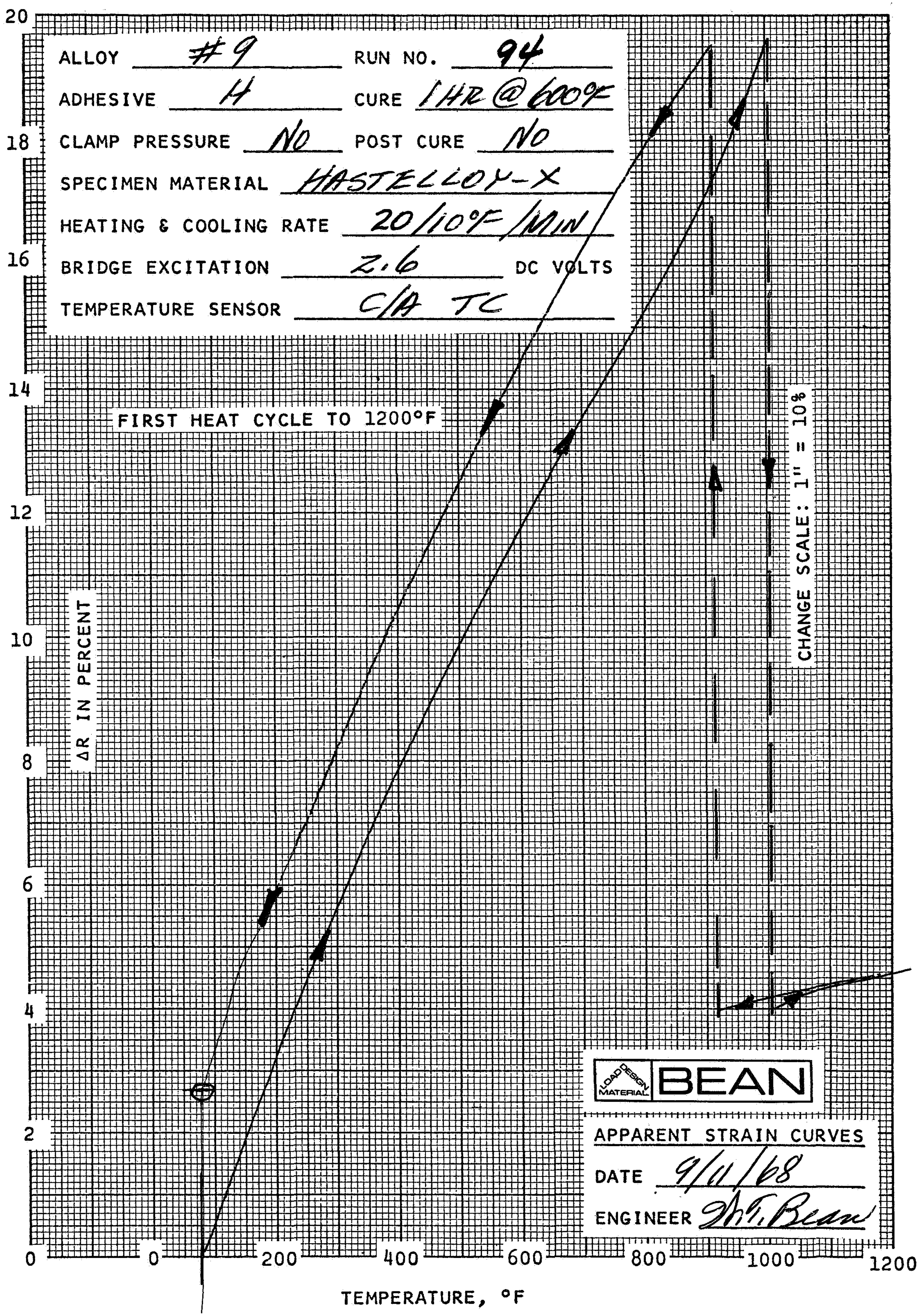

ALLOY #6
RUN NO. 85
ADHESIVE H
CURE 1HR @600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND HEAT CYCLE
(AFTER 1400°F HEAT CYCLE)
FIRST HEAT CYCLE TO 1400°F
ΔR IN PERCENT
TEMPERATURE IN HUNDREDS °F
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BEAN
LOAD DESIGN MATERIAL
APPARENT STRAIN CURVES
DATE 9/6/68
ENGINEER W.T. Bean

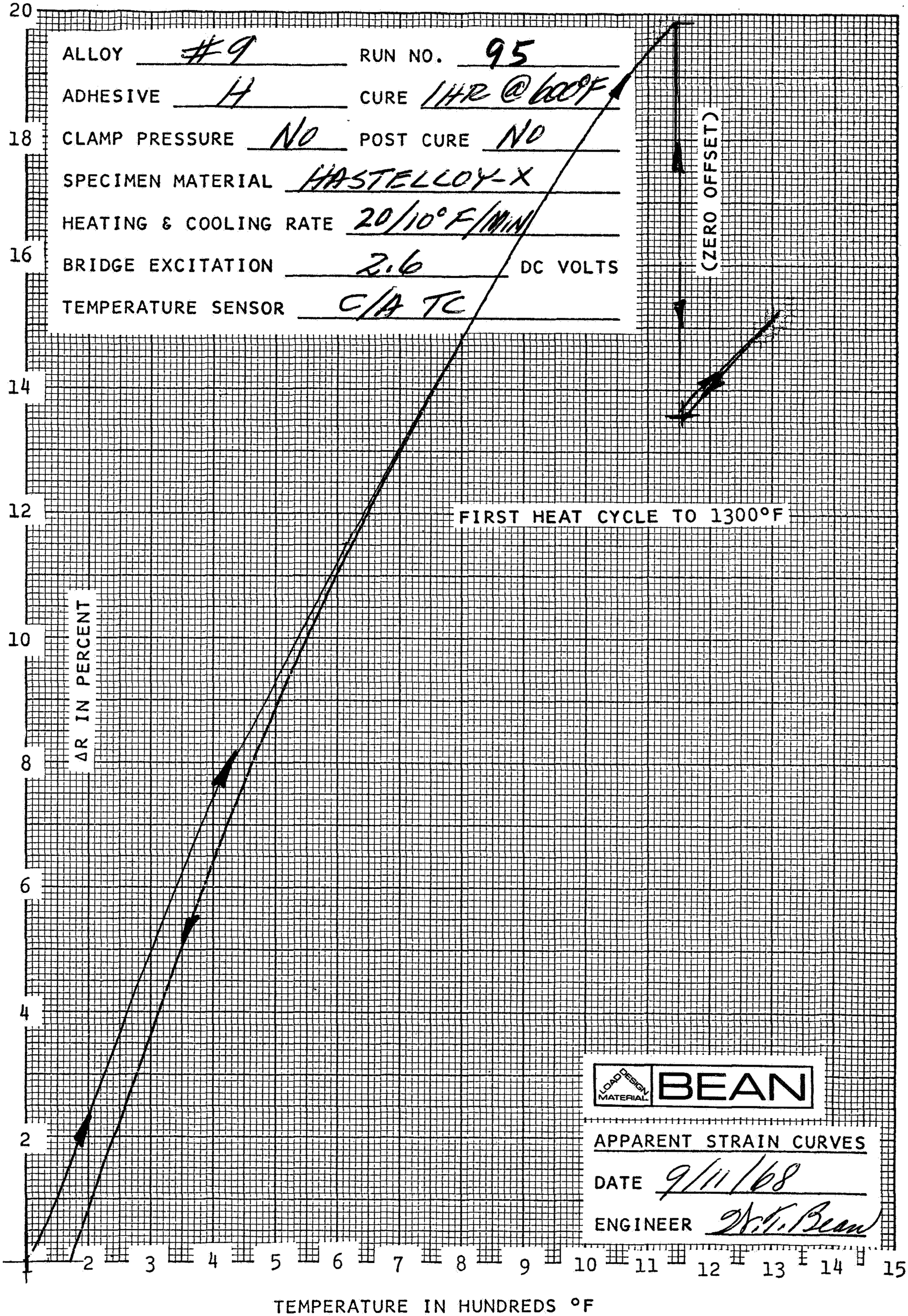

ALLOY #7
RUN NO. 88
ADHESIVE H
CURE 1HR@600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 25/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST HEAT CYCLE TO 950°F
CHANGE SCALE: 1" = 2%
45 MINUTES
20
10
ΔR IN PERCENT
0
1
2
3
4
5
6
7
8
9
10
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 9/9/68
ENGINEER W.T. Bean


ALLOY #7
RUN NO. 89
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 35/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR CA TC
SECOND CYCLE (1200°F MAX)
1 HR
30 MINUTES
75°F TO 1050°F (30 MIN)
ΔR IN PERCENT
TEMPERATURE, °F
0
1
2
3
4
5
6
7
8
9
10
0
200
400
600
800
1000
1200
BEAN
LOAD DESIGN MATERIAL
APPARENT STRAIN CURVES
DATE 9/10/68
ENGINEER D.R. Bean


ALLOY #8
RUN NO. 91
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 35/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST CYCLE (1200°F MAX)
SCALE: 1" = 2%
35 MINUTES
20
10
0
ΔR IN PERCENT
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
TEMPERATURE, °F
BEAN
APPARENT STRAIN CURVES
DATE 9/11/68
ENGINEER D.T. Bean


ALLOY #8
RUN NO. 92
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
SECOND HEAT CYCLE TO 1200°F
ΔR IN PERCENT
0
1
2
3
4
5
6
7
8
9
10
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 9/12/68
ENGINEER W.T. Bean


ALLOY #9
RUN NO. 94
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST HEAT CYCLE TO 1200°F
CHANGE SCALE: 1" = 10%
ΔR IN PERCENT
0
2
4
6
8
10
12
14
16
18
20
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 9/11/68
ENGINEER W.T. Bean



ALLOY #9
RUN NO. 95
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
(ZERO OFFSET)
FIRST HEAT CYCLE TO 1300°F
ΔR IN PERCENT
20
18
16
14
12
10
8
6
4
2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 9/11/68
ENGINEER W. T. Bean

ALLOY #10 RUN NO. 97

ADHESIVE H CURE 1HR @600°F

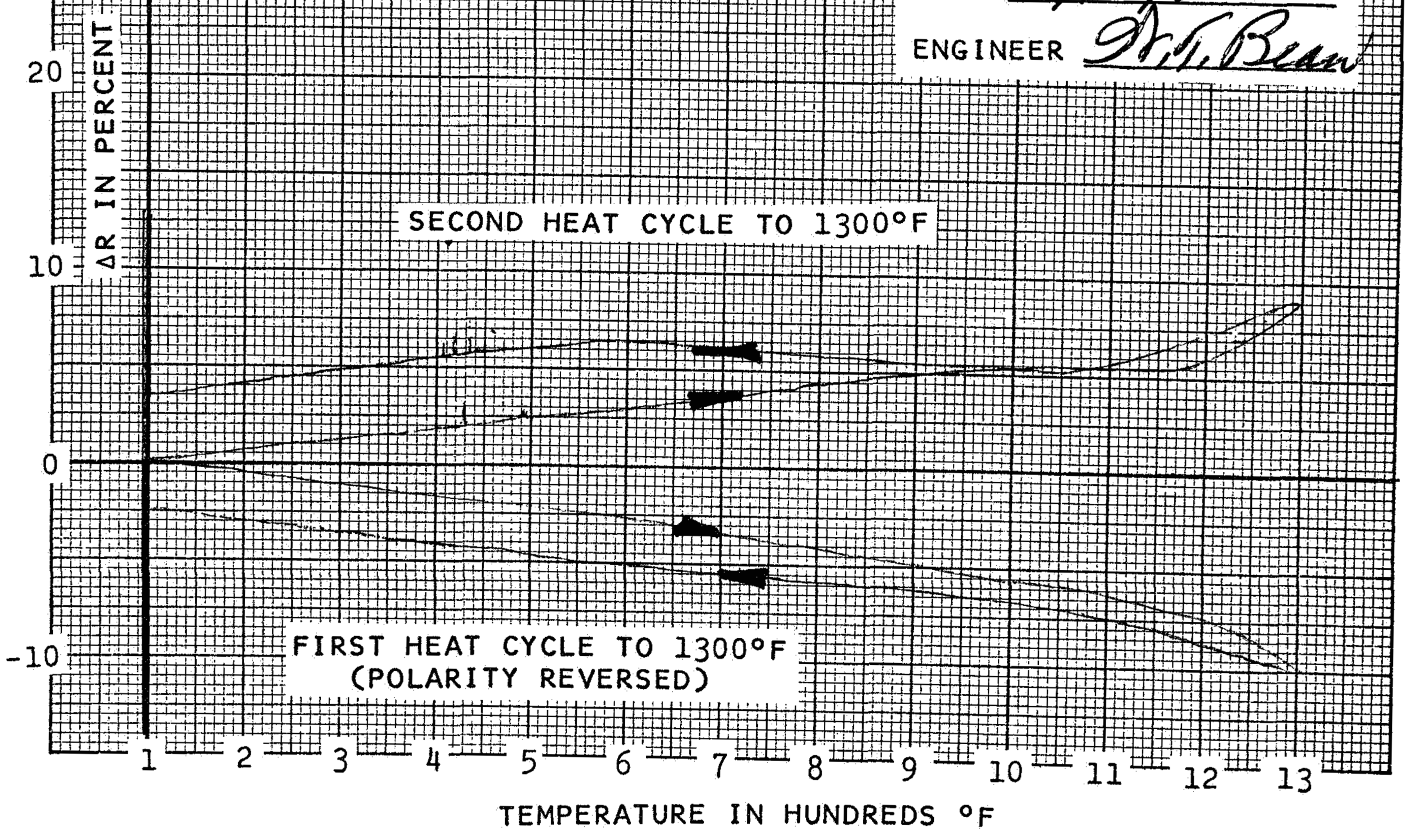
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/10°F/MIN

BRIDGE EXCITATION 2.6 DC VOLTS

TEMPERATURE SENSOR C/A TC

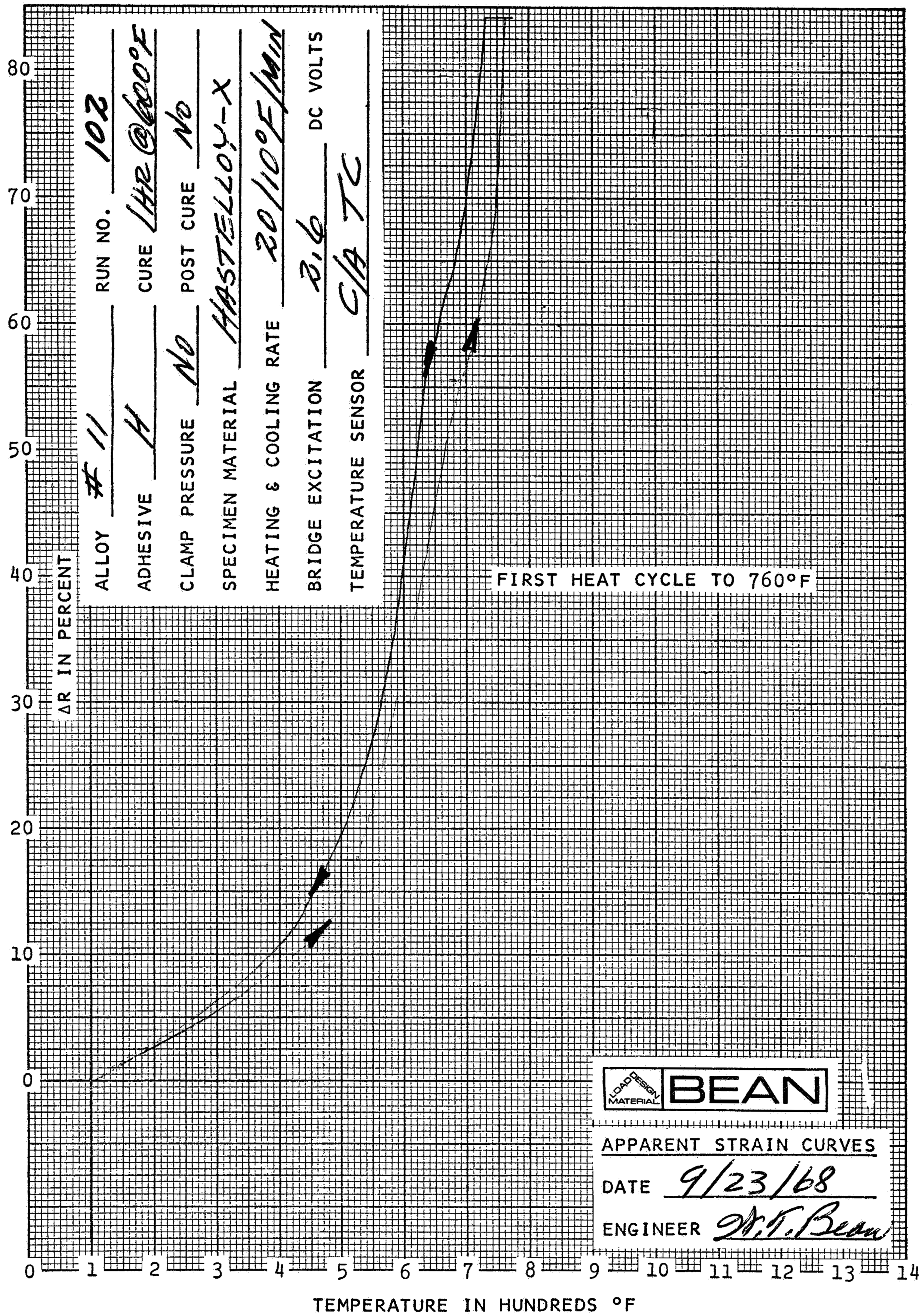


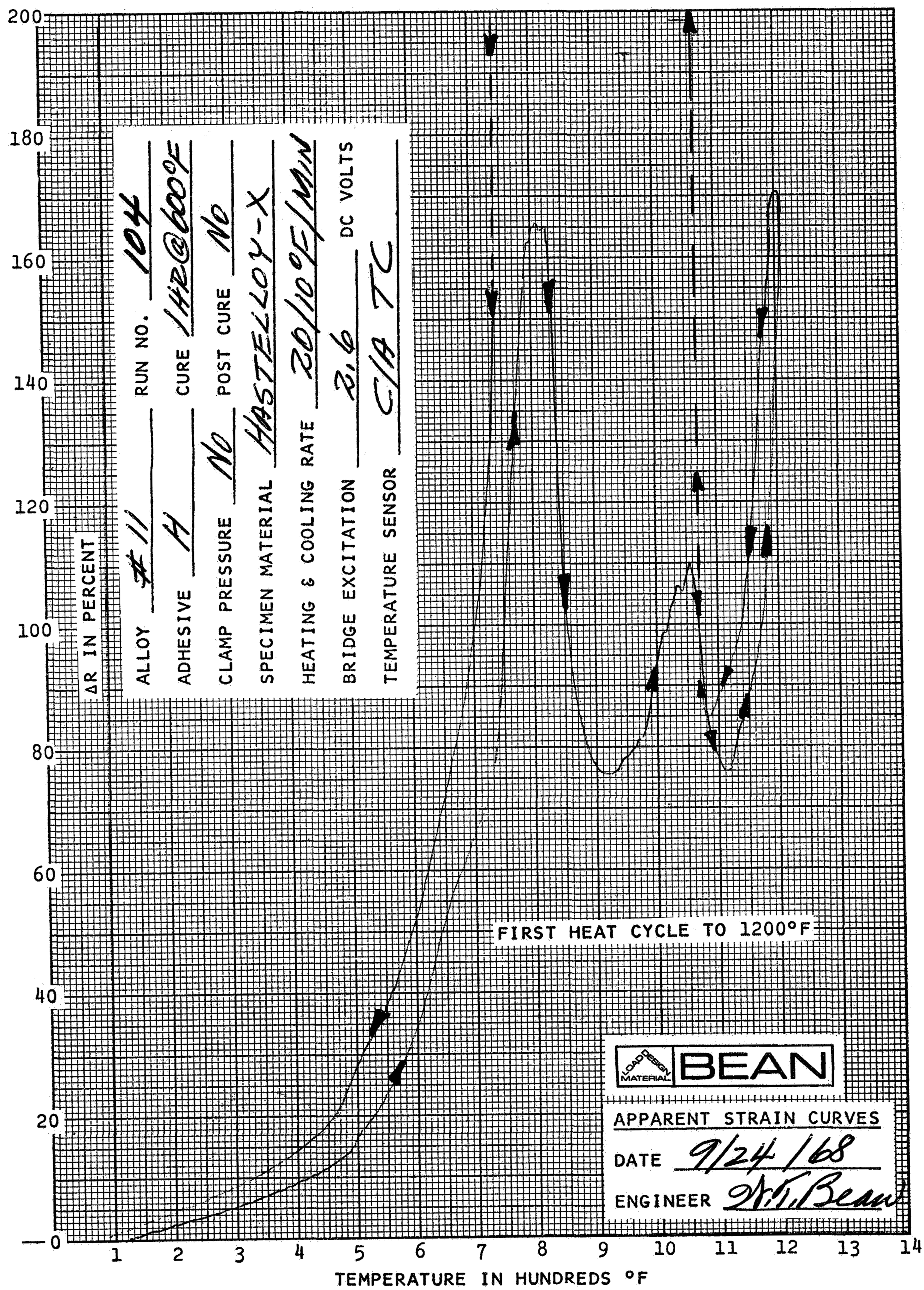
LOAD DESIGN MATERIAL BEAN

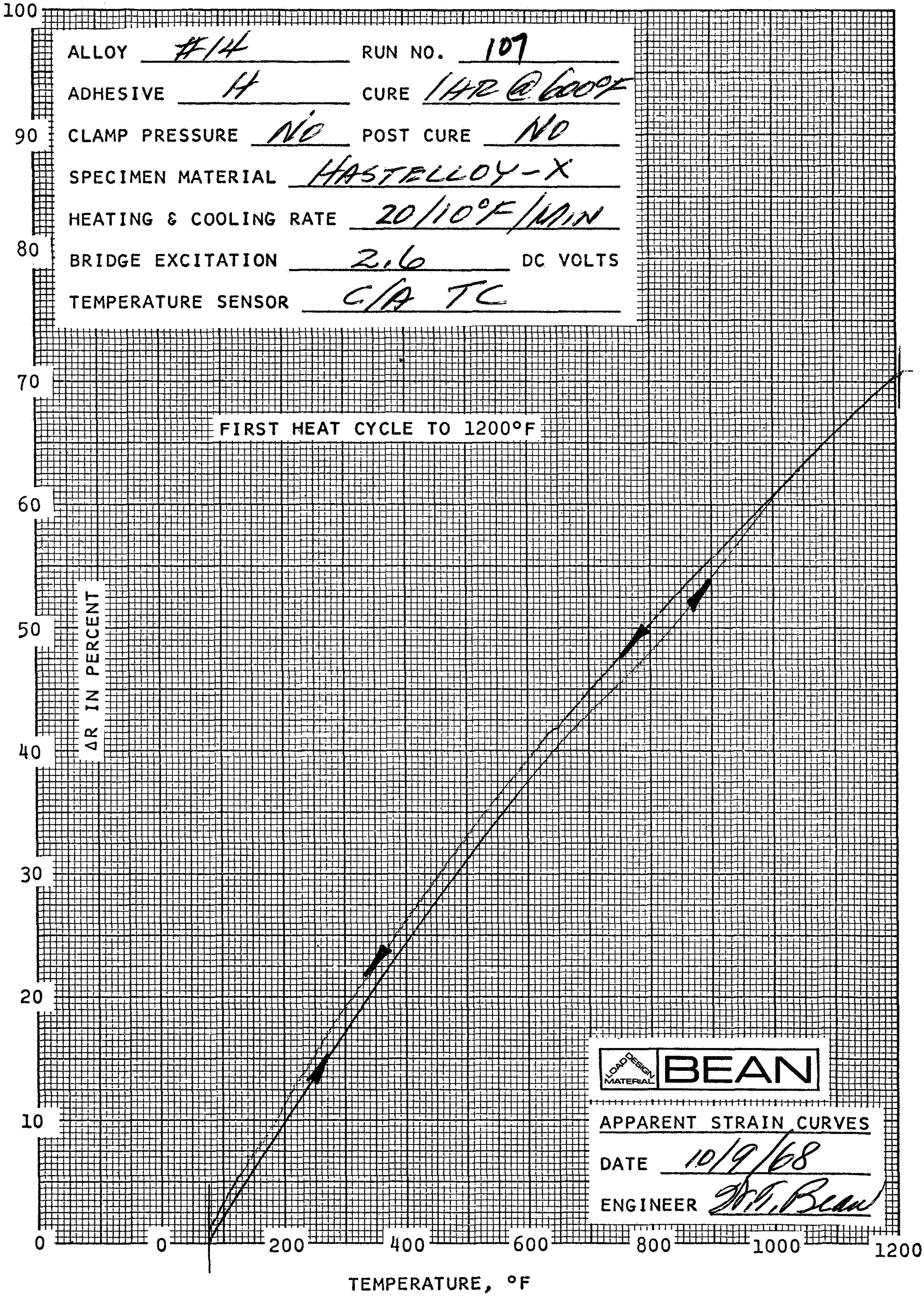
APPARENT STRAIN CURVES

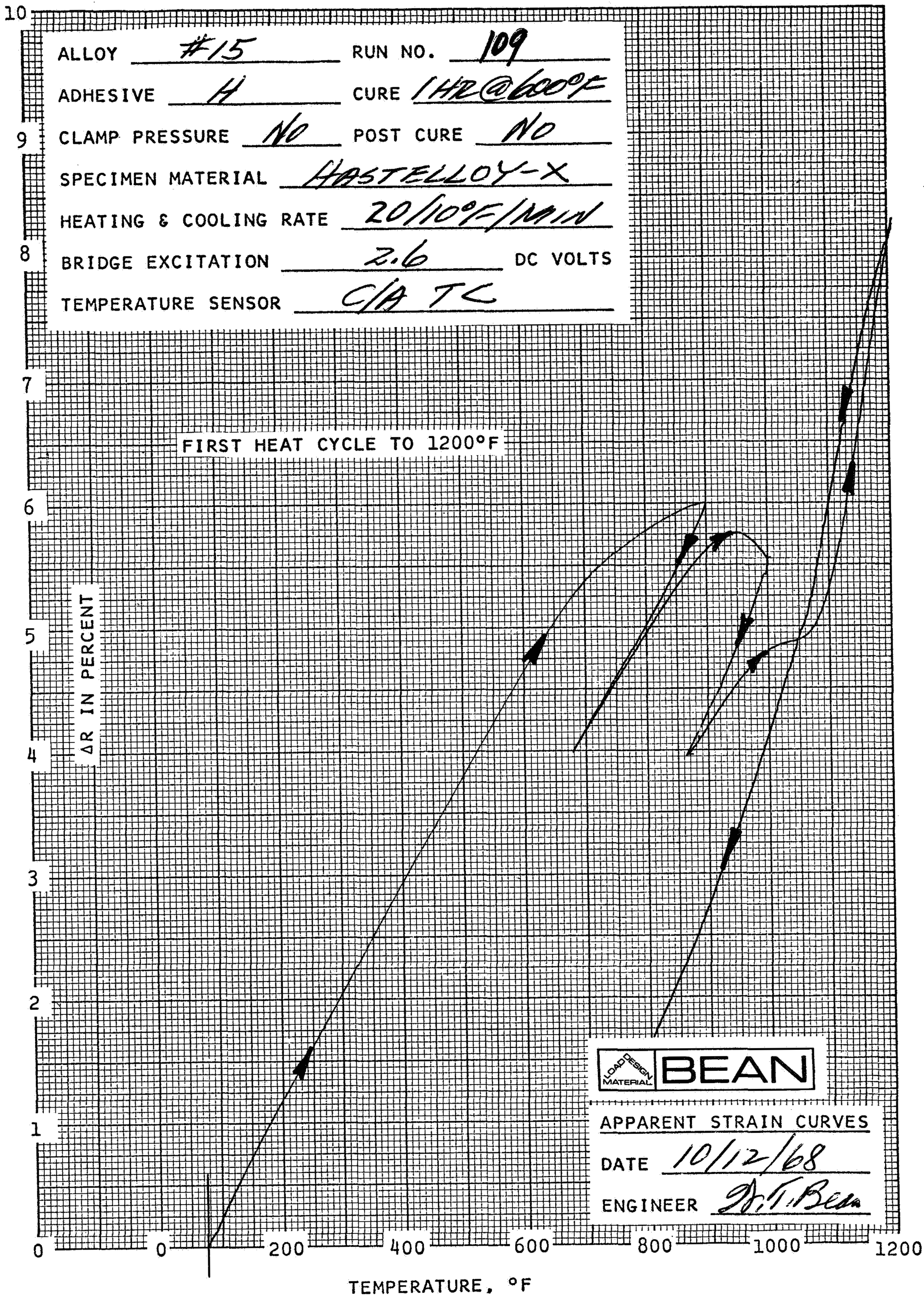
DATE 9/16/68

ENGINEER D. T. Bean


ALLOY #11
ADHESIVE H
CLAMP PRESSURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
RUN NO. 102
CURE 1HR @ 600°F
POST CURE NO
ΔR IN PERCENT
0
10
20
30
40
50
60
70
80
FIRST HEAT CYCLE TO 760°F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 9/23/68
ENGINEER W. T. Bean
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
TEMPERATURE IN HUNDREDS °F


ΔR IN PERCENT
TEMPERATURE IN HUNDREDS °F
0
20
40
60
80
100
120
140
160
180
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
ALLOY #11
RUN NO. 104
ADHESIVE H
CURE 1HR@600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST HEAT CYCLE TO 1200°F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 9/24/68
ENGINEER


ALLOY #14
RUN NO. 107
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST HEAT CYCLE TO 1200°F
ΔR IN PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 10/9/68
ENGINEER W.T. Bean


ALLOY #15
RUN NO. 109
ADHESIVE H
CURE 1HR@600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 2.6 DC VOLTS
TEMPERATURE SENSOR C/A TC
FIRST HEAT CYCLE TO 1200°F
ΔR IN PERCENT
TEMPERATURE, °F
0
1
2
3
4
5
6
7
8
9
10
0
200
400
600
800
1000
1200
LOAD DESIGN MATERIAL
BEAN
APPARENT STRAIN CURVES
DATE 10/12/68
ENGINEER D.T. Bean

V. STRAIN GAGE DESIGN

A strain gage grid was designed utilizing platinum Alloys # 13 and # 3 (Figure 7). The grid was cemented to a high-temperature test specimen of Hastelloy-X. Figure 8 shows the various apparent strain curves obtained by stabilization at 1300°F.

Tests also were conducted with various lengths of the compensating filament, Alloy # 3, in order to rotate the temperature coefficient (T-C) curve (Runs # 202, # 203, and # 209). These runs are compared in Figure 9.

Temperature compensated strain gages were designed and tested on the materials listed in Table VIII. The gage may be designed for other materials by using Figures 10 and 11.

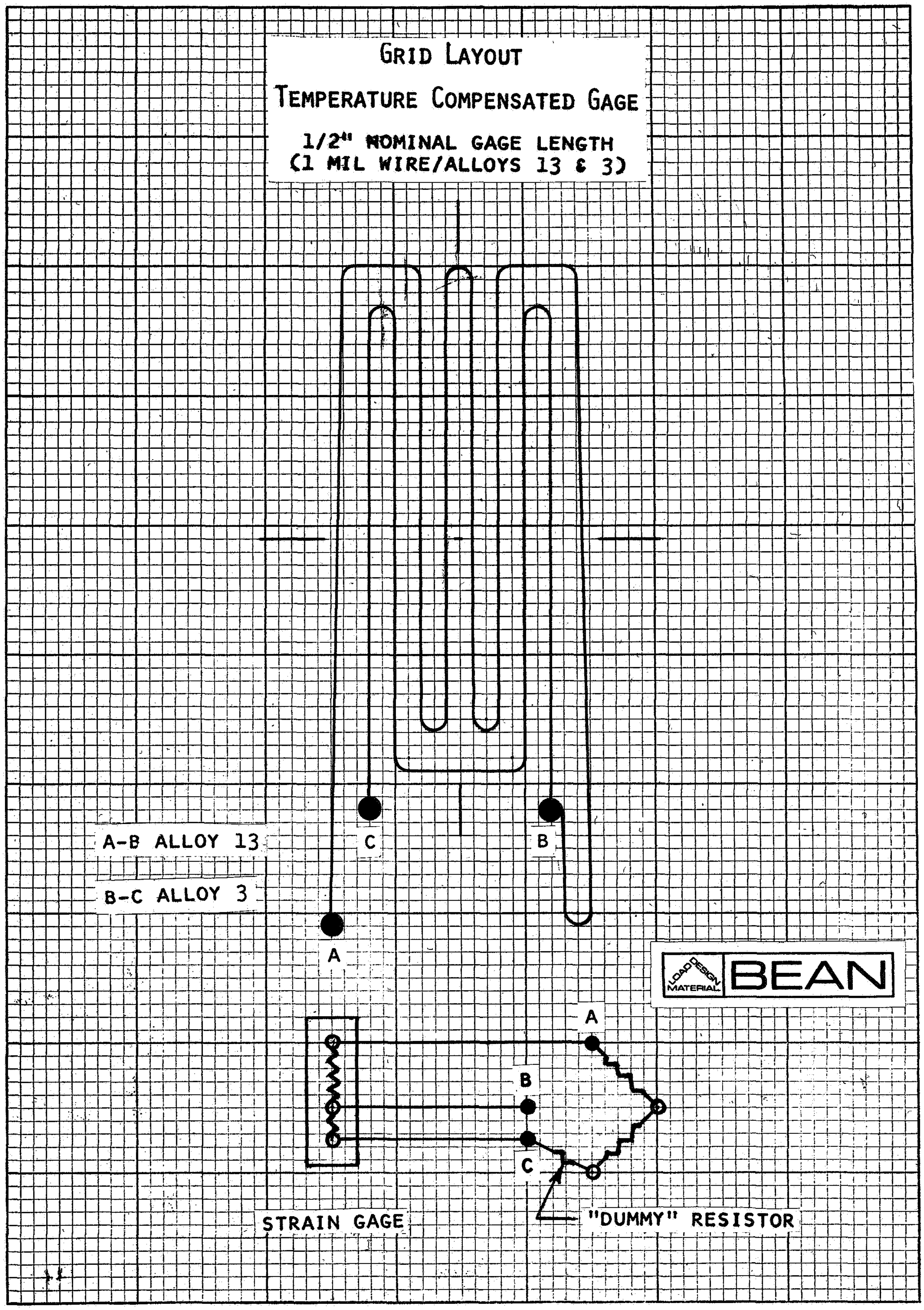

GRID LAYOUT
TEMPERATURE COMPENSATED GAGE
1/2" NOMINAL GAGE LENGTH
(1 MIL WIRE/ALLOYS 13 & 3)
A-B ALLOY 13
B-C ALLOY 3
C
B
A
LOAD DESIGN MATERIAL
BEAN
A
B
C
STRAIN GAGE
"DUMMY" RESISTOR

FIGURE 7.

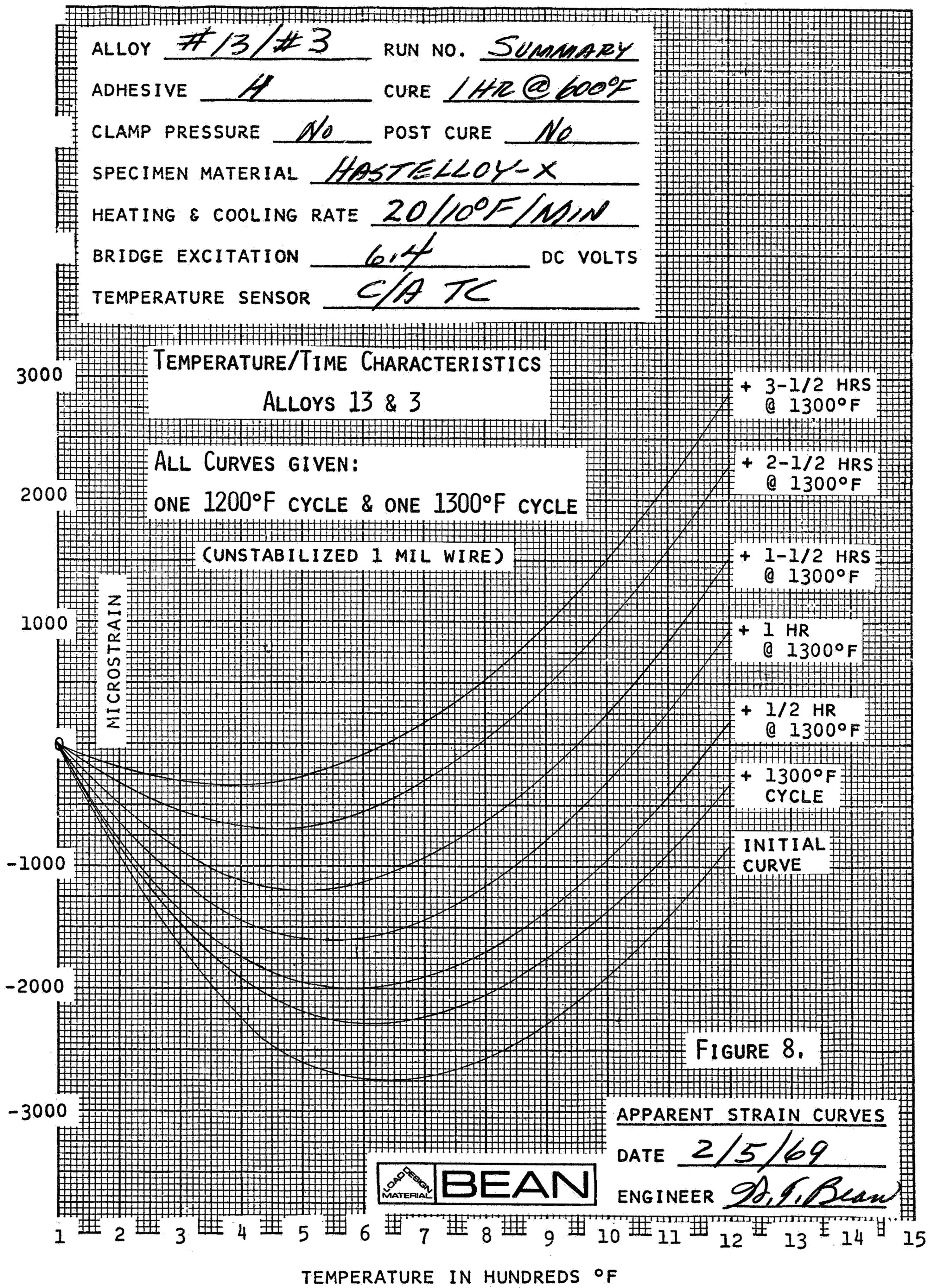
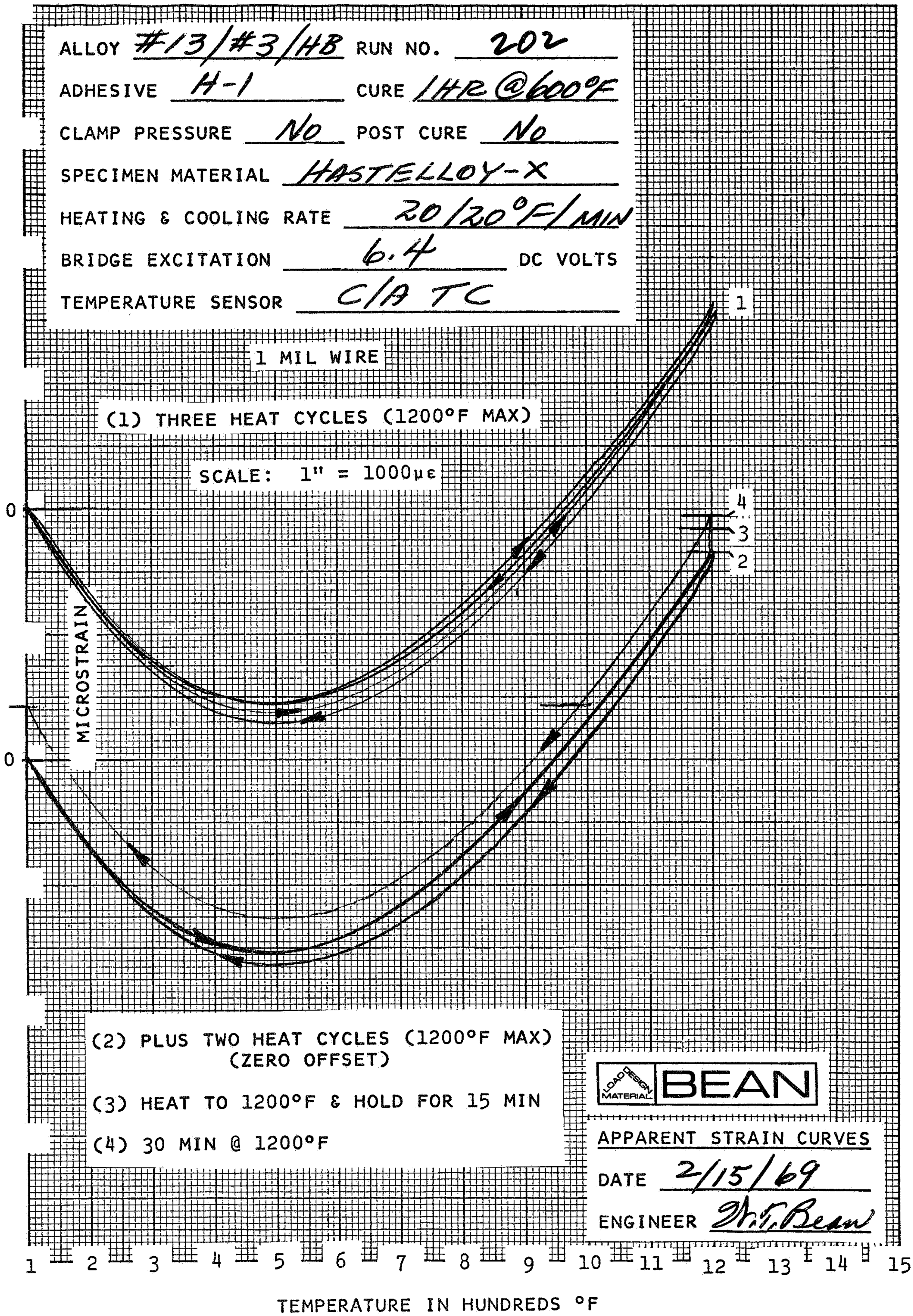
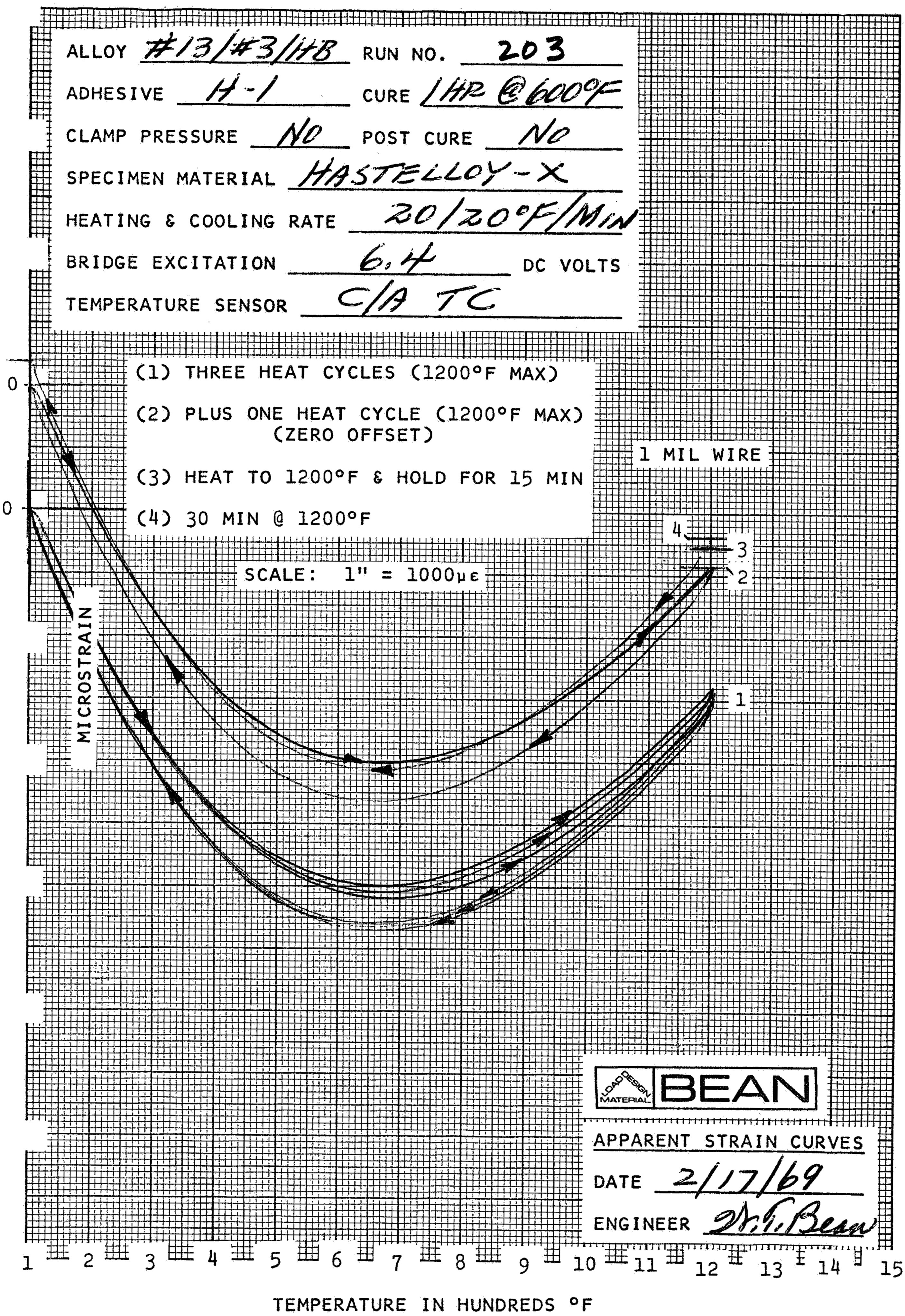
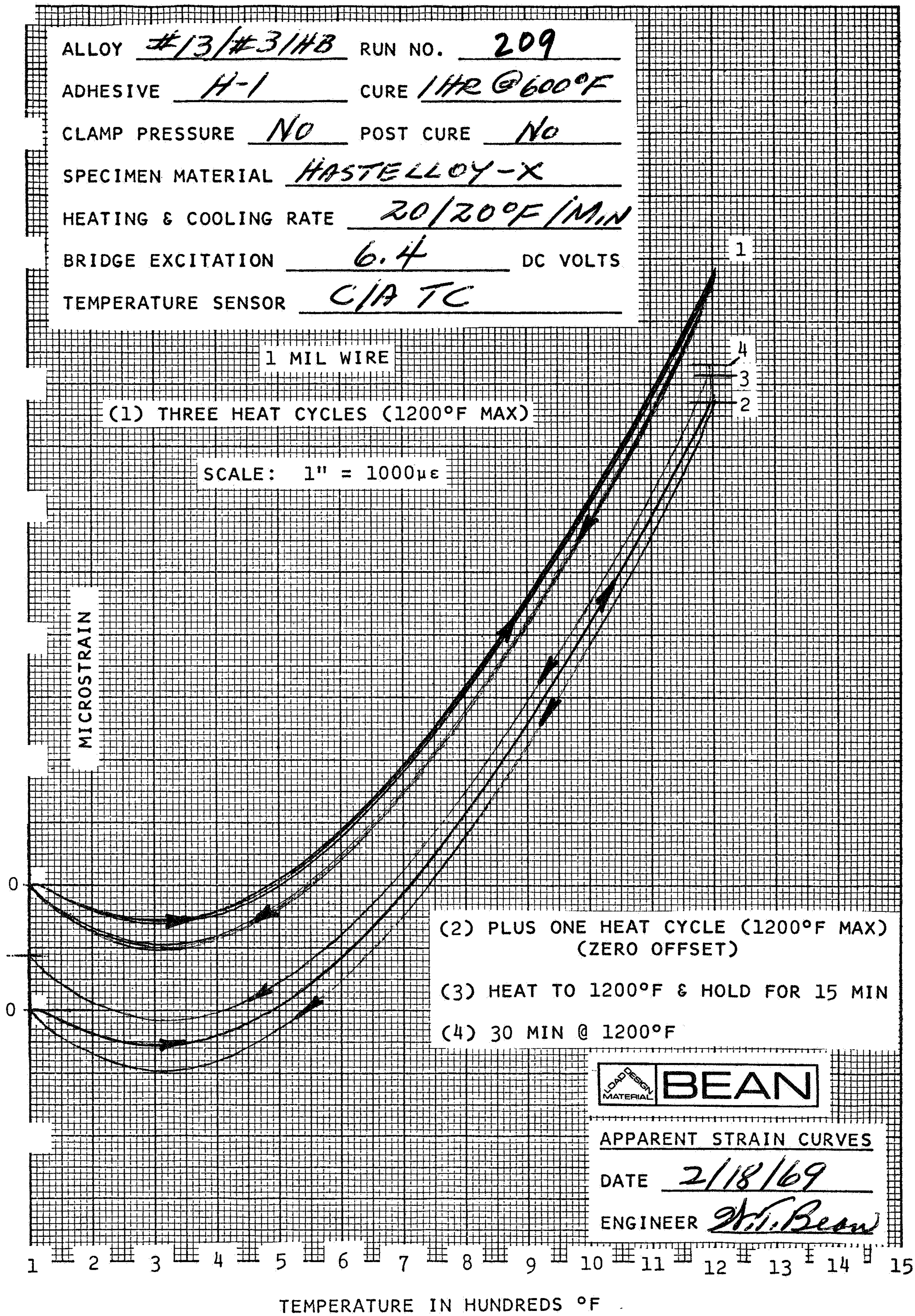

ALLOY #13/#3
RUN NO. SUMMARY
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/10°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
TEMPERATURE/TIME CHARACTERISTICS
ALLOYS 13 & 3
ALL CURVES GIVEN:
ONE 1200°F CYCLE & ONE 1300°F CYCLE
(UNSTABILIZED 1 MIL WIRE)
MICROSTRAIN
3000
2000
1000
-1000
-2000
-3000
+ 3-1/2 HRS @ 1300°F
+ 2-1/2 HRS @ 1300°F
+ 1-1/2 HRS @ 1300°F
+ 1 HR @ 1300°F
+ 1/2 HR @ 1300°F
+ 1300°F CYCLE
INITIAL CURVE
APPARENT STRAIN CURVES
DATE 2/5/69
ENGINEER D. F. Bean
LOAD DESIGN MATERIAL BEAN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F

FIGURE 8.


ALLOY #13/#3/HB
RUN NO. 202
ADHESIVE H-1
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
1 MIL WIRE
(1) THREE HEAT CYCLES (1200°F MAX)
SCALE: 1" = 1000με
MICROSTRAIN
0
0
1
4
3
2
(2) PLUS TWO HEAT CYCLES (1200°F MAX)
(ZERO OFFSET)
(3) HEAT TO 1200°F & HOLD FOR 15 MIN
(4) 30 MIN @ 1200°F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 2/15/69
ENGINEER W.T. Bean
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TEMPERATURE IN HUNDREDS °F


ALLOY #13/#3/HB
RUN NO. 203
ADHESIVE H-1
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
(1) THREE HEAT CYCLES (1200°F MAX)
(2) PLUS ONE HEAT CYCLE (1200°F MAX) (ZERO OFFSET)
(3) HEAT TO 1200°F & HOLD FOR 15 MIN
(4) 30 MIN @ 1200°F
1 MIL WIRE
SCALE: 1" = 1000µε
MICROSTRAIN
0
0
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 2/17/69
ENGINEER N.T. Bean


ALLOY #13/#31HB RUN NO. 209
ADHESIVE H-1 CURE 1HR @600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
1 MIL WIRE
(1) THREE HEAT CYCLES (1200°F MAX)
SCALE: 1" = 1000με
MICROSTRAIN
1
4
3
2
0
0
(2) PLUS ONE HEAT CYCLE (1200°F MAX)
(ZERO OFFSET)
(3) HEAT TO 1200°F & HOLD FOR 15 MIN
(4) 30 MIN @ 1200°F
LOAD DESIGN MATERIAL BEAN
APPARENT STRAIN CURVES
DATE 2/18/69
ENGINEER W.T. Bean
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F

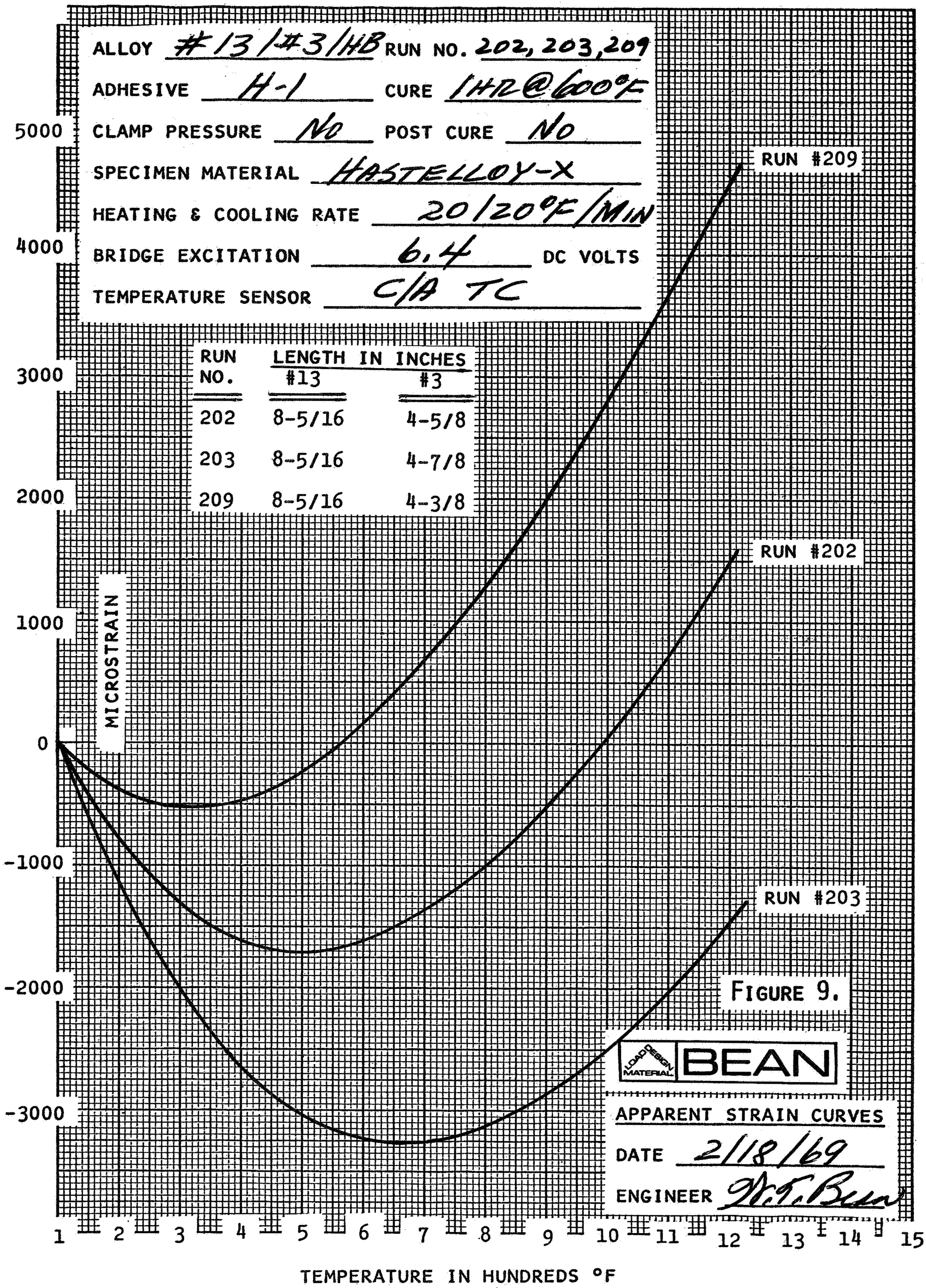

ALLOY #13/#3/HB RUN NO. 202, 203, 209
ADHESIVE H-1 CURE 1HR @ 600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
RUN NO. | LENGTH IN INCHES #13 | #3
202 8-5/16 4-5/8
203 8-5/16 4-7/8
209 8-5/16 4-3/8
RUN #209
RUN #202
RUN #203
MICROSTRAIN
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TEMPERATURE IN HUNDREDS °F
BEAN
LOAD DESIGN MATERIAL
APPARENT STRAIN CURVES
DATE 2/18/69
ENGINEER W.T. Bean
FIGURE 9.

Table VIII

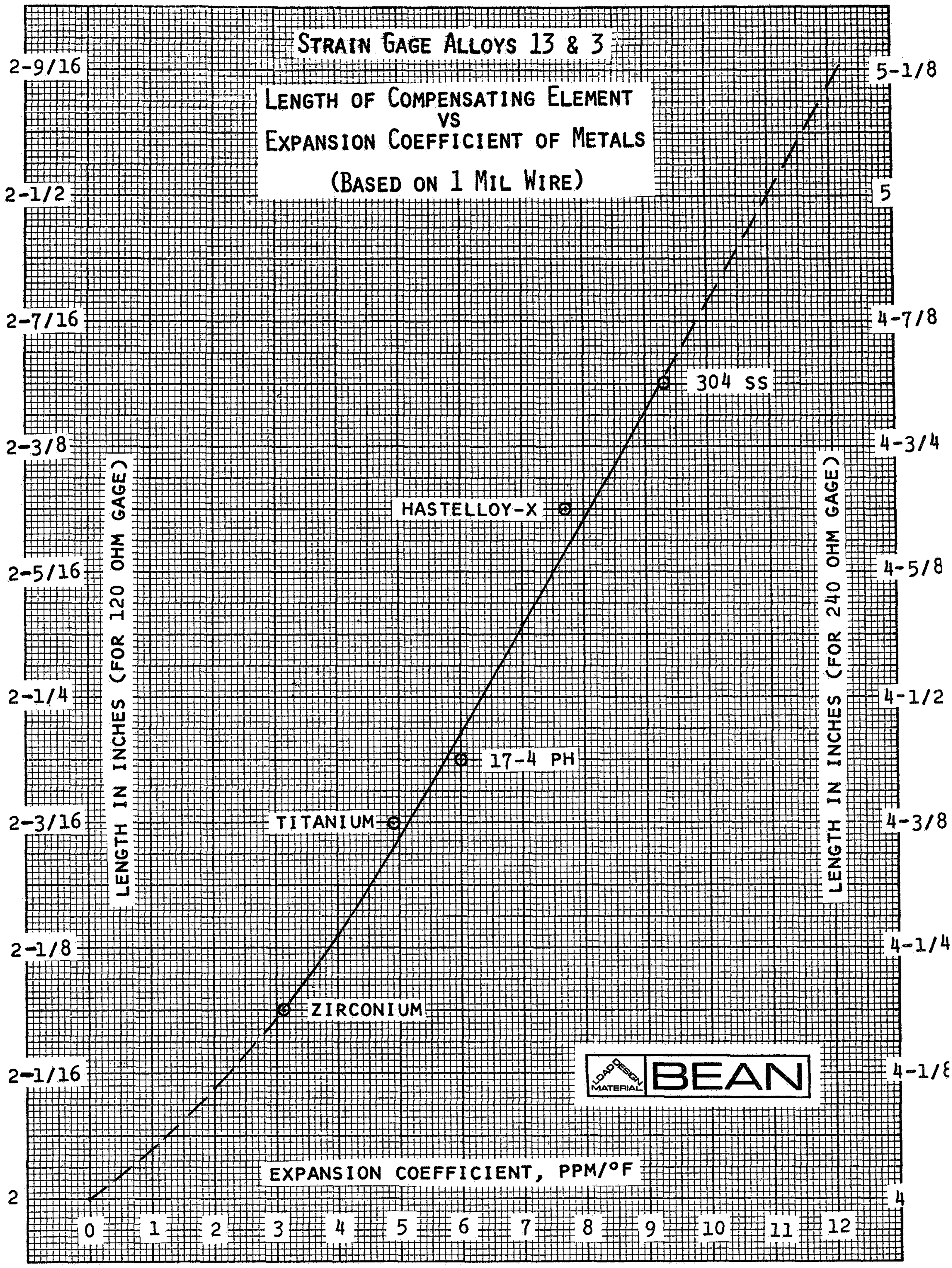
STRAIN GAGE ALLOYS 13 & 3

Typical Compensating Elements
for
120 Ohm Gages*

(Based on 1 Mil Wire)

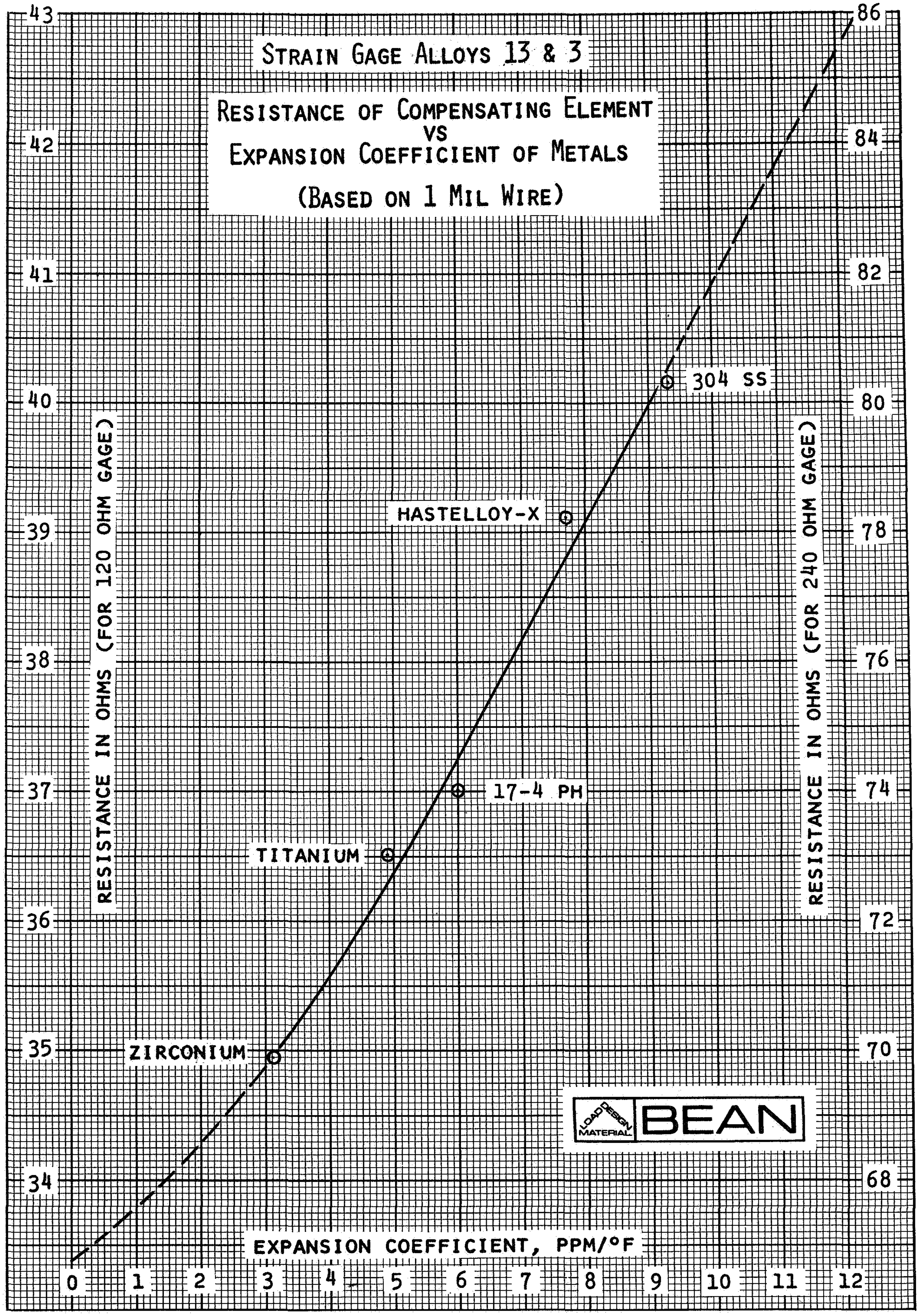
Specimen Material	Expansion Coefficient PPM/°F	Length in Inches	Compensating Resistance Ohms	"Dummy" Resistance Ohms
Zirconium	3.1	2-3/32	34.95	85.05
Titanium	4.9	2-3/16	36.51	83.49
17-4 PH	6.0	2-7/32	37.03	82.97
Hastelloy-X	7.7	2-11/32	39.12	80.88
304 SS	9.3	2-13/32	40.16	79.84

*Nominal length of 120 Ω active element (#13) is 4-3/16" @ 75°F



STRAIN GAGE ALLOYS 13 & 3
LENGTH OF COMPENSATING ELEMENT
VS
EXPANSION COEFFICIENT OF METALS
(BASED ON 1 MIL WIRE)
304 SS
HASTELLOY-X
17-4 PH
TITANIUM
ZIRCONIUM
LOAD DESIGN MATERIAL
BEAN
EXPANSION COEFFICIENT, PPM/°F
LENGTH IN INCHES (FOR 120 OHM GAGE)
LENGTH IN INCHES (FOR 240 OHM GAGE)
2-9/16
2-1/2
2-7/16
2-3/8
2-5/16
2-1/4
2-3/16
2-1/8
2-1/16
2
5-1/8
5
4-7/8
4-3/4
4-5/8
4-1/2
4-3/8
4-1/4
4-1/8
4
0
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE 10.



STRAIN GAGE ALLOYS 13 & 3
RESISTANCE OF COMPENSATING ELEMENT
VS
EXPANSION COEFFICIENT OF METALS
(BASED ON 1 MIL WIRE)
RESISTANCE IN OHMS (FOR 120 OHM GAGE)
RESISTANCE IN OHMS (FOR 240 OHM GAGE)
EXPANSION COEFFICIENT, PPM/°F
304 SS
HASTELLOY-X
17-4 PH
TITANIUM
ZIRCONIUM
43
42
41
40
39
38
37
36
35
34
86
84
82
80
78
76
74
72
70
68
0
1
2
3
4
5
6
7
8
9
10
11
12
LOAD DESIGN MATERIAL
BEAN

FIGURE 11.

VI. STRAIN GAGE EVALUATION

Temperature Compensation

Using the preceding information, apparent strain curves were obtained as follows:

Specimen Material	Run No.
Aluminum, 2024	234
Zirconium	223
Titanium, 6AL4V	211
Hastelloy-X	235
Hastelloy-X	230
Stainless Steel, 304	214

During the initial heat cycle a zero offset is evident when the strain gage filament encounters plastic deformation (Runs # 235, # 230, # 214). The magnitude of the offset may be predicted by considering the coefficient of expansion of the specimen material and the applied mechanical strain. The gage filament performs in an elastic manner on the recovery cycle.

ALLOY #13/#3/HB RUN NO. 234

ADHESIVE H-1 CURE 1 hr @ 600°F

CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL 2024 ANNEALED

HEATING & COOLING RATE 20/20°F/MIN

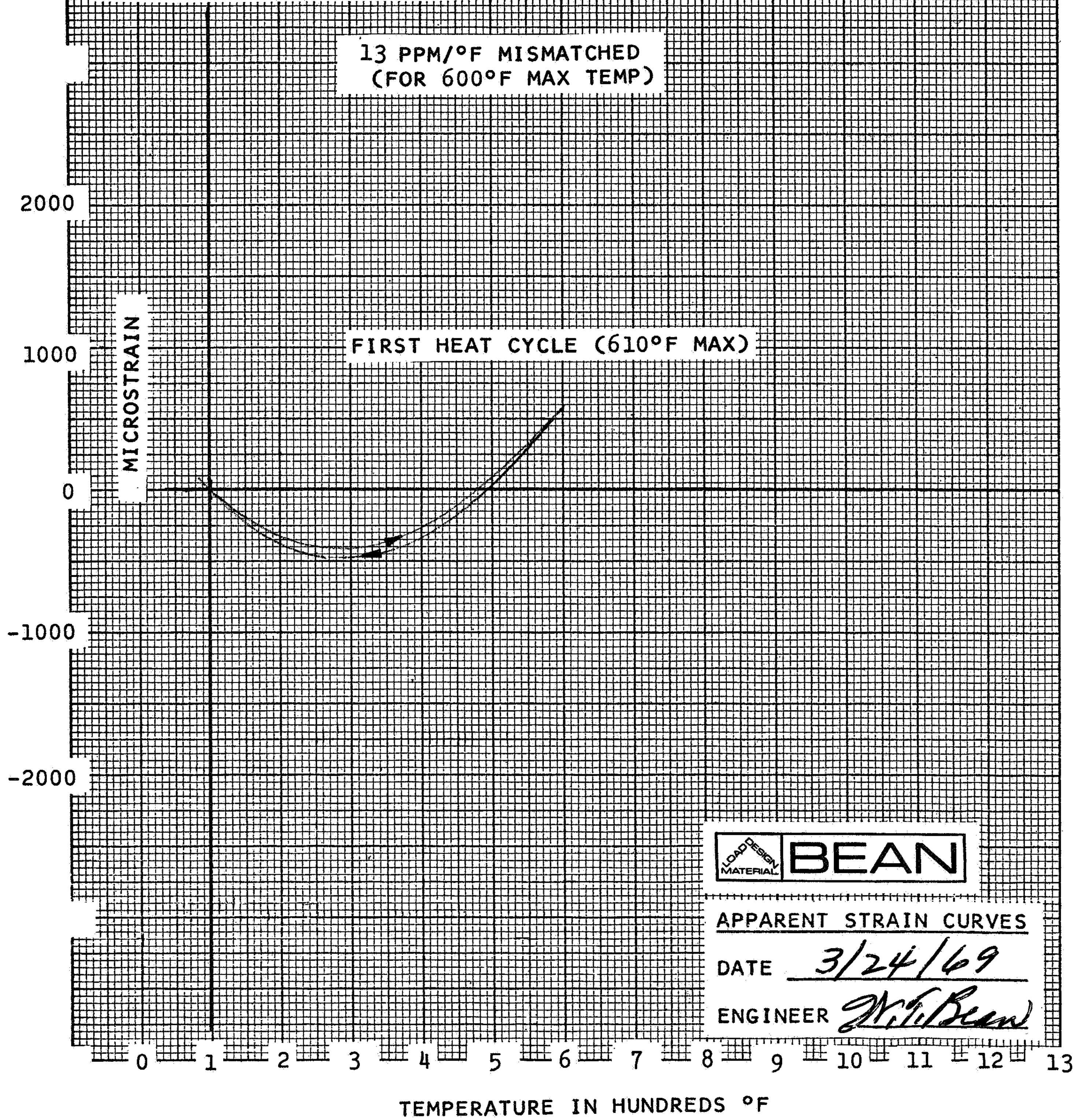
BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC

1 MIL WIRE

#13 8-3/8"

#3 4-11/16"



BEAN

APPARENT STRAIN CURVES

DATE 3/24/69

ENGINEER W. T. Bean

ALLOY #13/#3/HA RUN NO. 223

ADHESIVE H-1 CURE 1HR @ 600°F

CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL ZIRCONIUM

HEATING & COOLING RATE 20/20°F/MIN

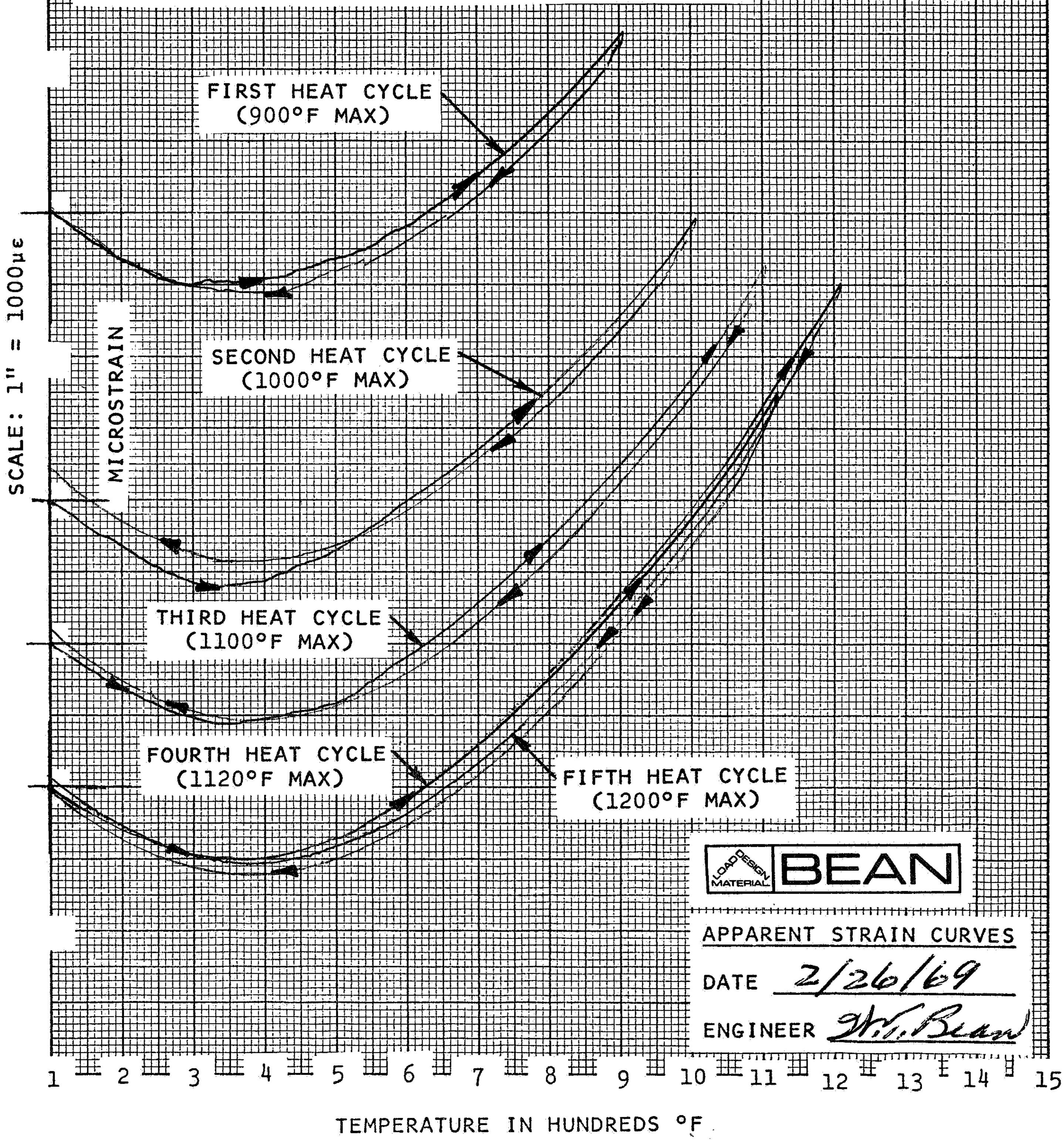
BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC

1 MIL WIRE

#13 8-3/8"

#3 4-1/8"

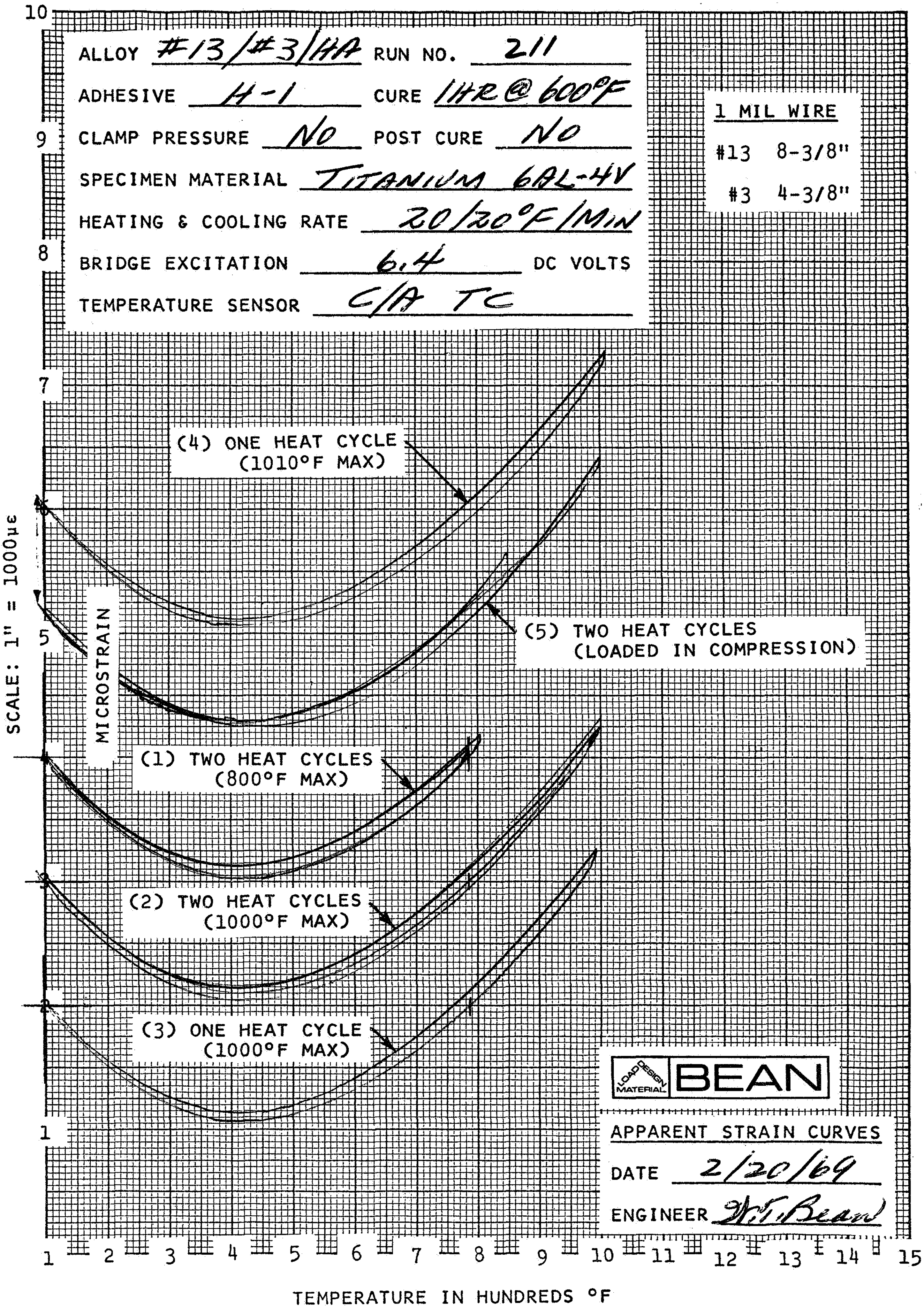


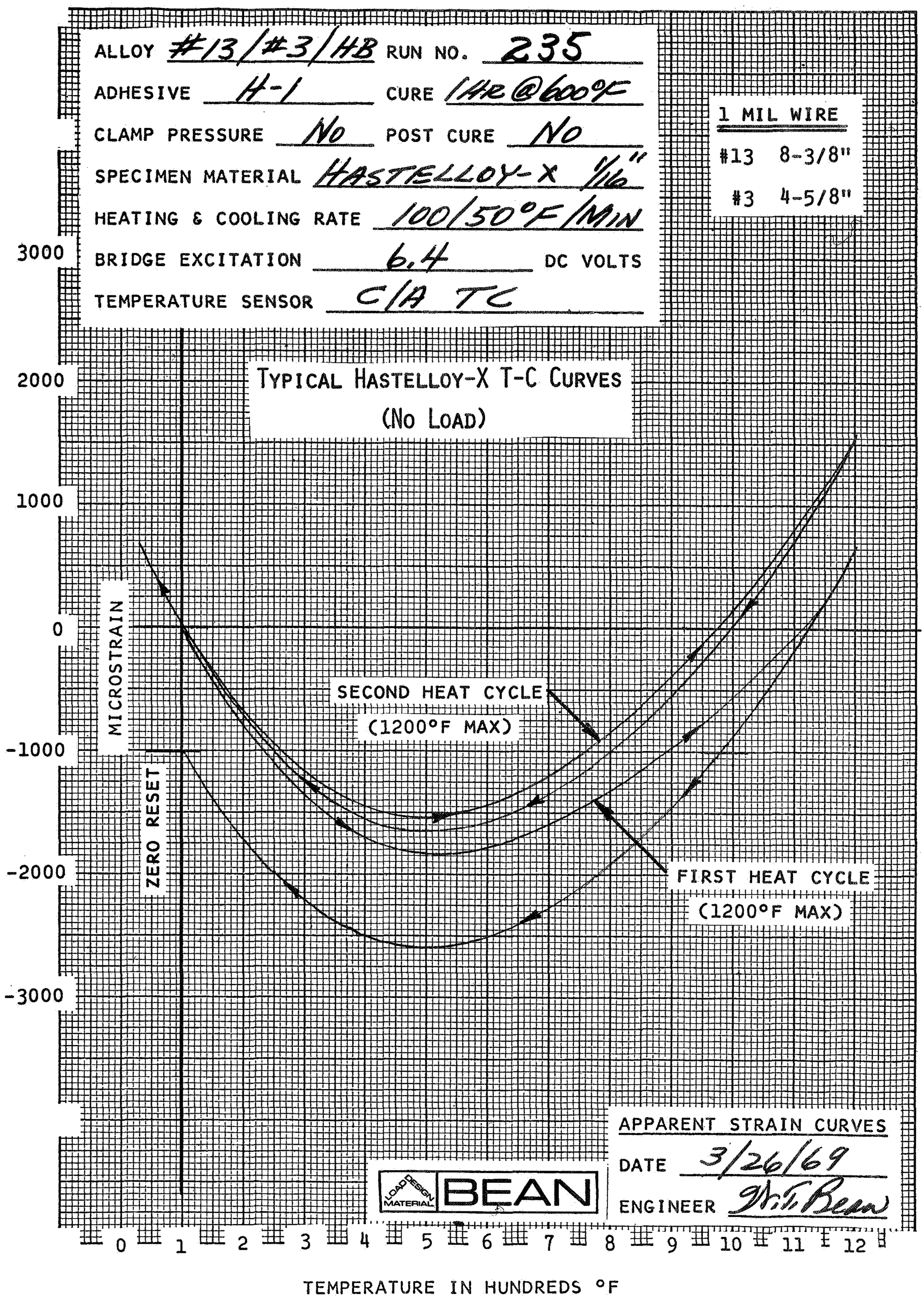
LOAD DESIGN MATERIAL BEAN

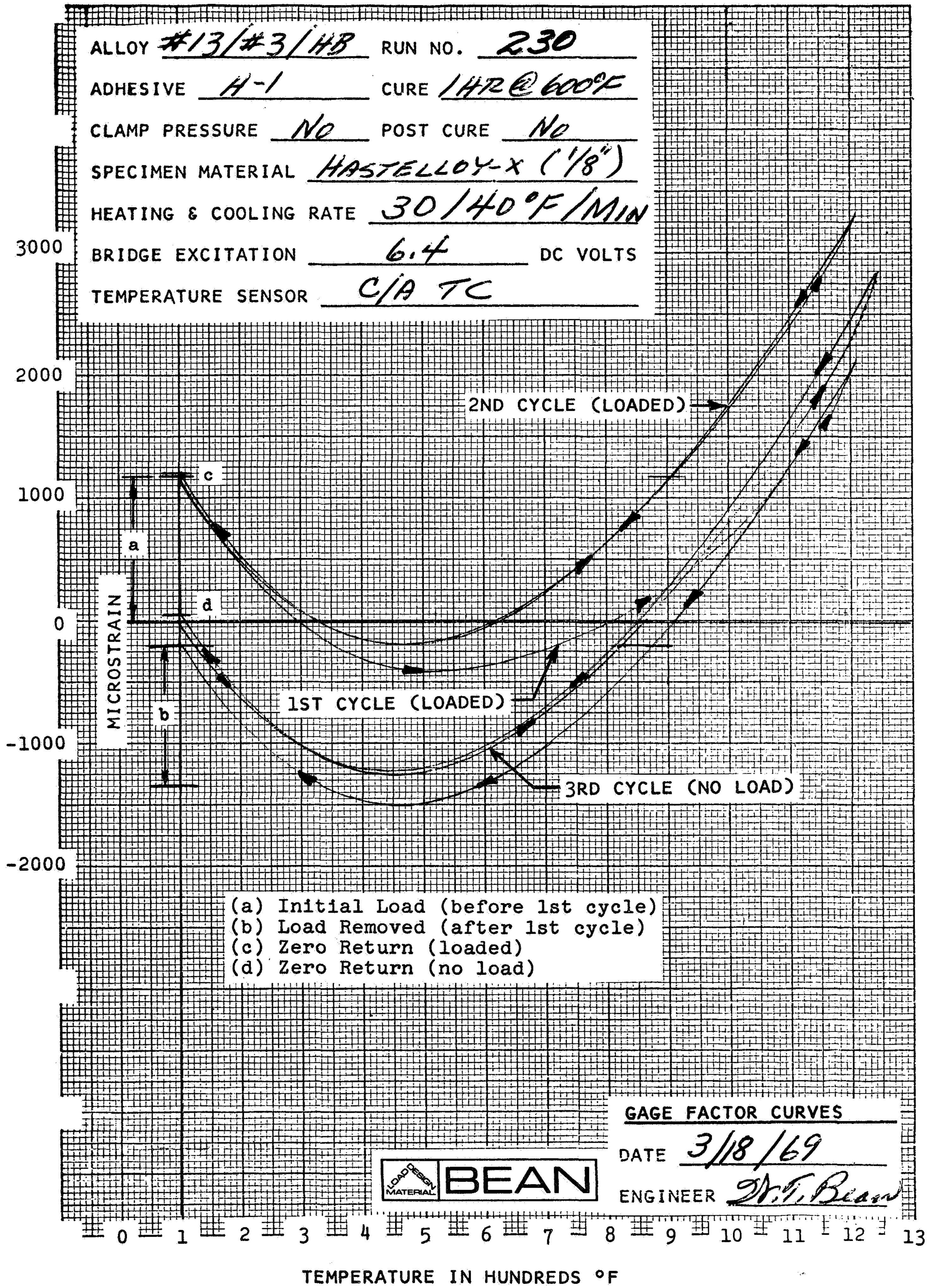
APPARENT STRAIN CURVES

DATE 2/26/69

ENGINEER W. V. Bean


ALLOY #13/#3/HA RUN NO. 211
ADHESIVE H-1 CURE 1HR @ 600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL TITANIUM 6AL-4V
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
1 MIL WIRE
#13 8-3/8"
#3 4-3/8"
(4) ONE HEAT CYCLE (1010°F MAX)
(5) TWO HEAT CYCLES (LOADED IN COMPRESSION)
(1) TWO HEAT CYCLES (800°F MAX)
(2) TWO HEAT CYCLES (1000°F MAX)
(3) ONE HEAT CYCLE (1000°F MAX)
SCALE: 1" = 1000με
MICROSTRAIN
1
5
7
8
9
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TEMPERATURE IN HUNDREDS °F
BEAN
LOAD DESIGN MATERIAL
APPARENT STRAIN CURVES
DATE 2/20/69
ENGINEER W.T. Bean


ALLOY #13/#3/HB RUN NO. 235
ADHESIVE H-1 CURE 1HR @ 600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X 1/16"
HEATING & COOLING RATE 100/50°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
1 MIL WIRE
#13 8-3/8"
#3 4-5/8"
TYPICAL HASTELLOY-X T-C CURVES
(NO LOAD)
3000
2000
1000
0
-1000
-2000
-3000
MICROSTRAIN
ZERO RESET
SECOND HEAT CYCLE
(1200°F MAX)
FIRST HEAT CYCLE
(1200°F MAX)
APPARENT STRAIN CURVES
DATE 3/26/69
ENGINEER W.T. Bean
BEAN
0
1
2
3
4
5
6
7
8
9
10
11
12
TEMPERATURE IN HUNDREDS °F


ALLOY #13/#3/HB RUN NO. 230
ADHESIVE H-1 CURE 1HR @ 600°F
CLAMP PRESSURE NO POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X (1/8")
HEATING & COOLING RATE 30/40°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
3000
2000
1000
0
-1000
-2000
MICROSTRAIN
a
b
c
d
2ND CYCLE (LOADED)
1ST CYCLE (LOADED)
3RD CYCLE (NO LOAD)
(a) Initial Load (before 1st cycle)
(b) Load Removed (after 1st cycle)
(c) Zero Return (loaded)
(d) Zero Return (no load)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
TEMPERATURE IN HUNDREDS °F
GAGE FACTOR CURVES
DATE 3/18/69
ENGINEER
LOAD DESIGN MATERIAL BEAN

ALLOY #13/#3/HB RUN NO. 214

ADHESIVE H-1 CURE 1HR @ 600°F

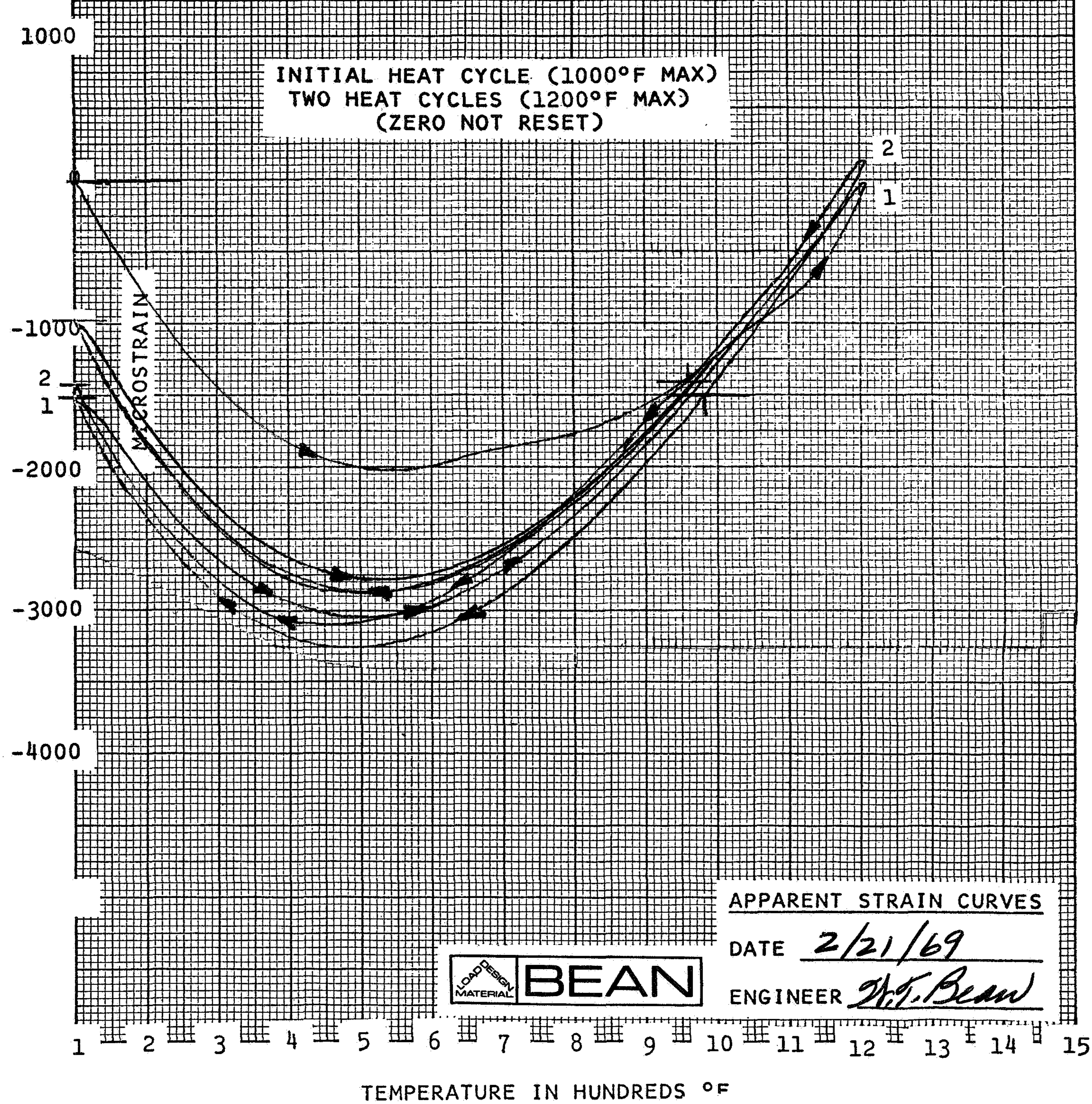
CLAMP PRESSURE No POST CURE No

SPECIMEN MATERIAL 304 SS (1/4")

HEATING & COOLING RATE 10/20°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



APPARENT STRAIN CURVES

DATE 2/21/69

LOAD DESIGN MATERIAL BEAN

ENGINEER W.T. Bean

Gage Factor vs. Temperature

In order to determine gage factor vs. temperature, a strain gage was mounted on the gage-factor calibration bar (Figure 12). "First" cycle point-by-point data was obtained at various temperatures (Table IX). The second cycle T-C curve is shown (Run # 200). The third heat cycle (no load) is compared with the fourth heat cycle (fixture loaded) (Run # 201). The reduction in gage factor with increasing temperature is apparent from closer ordinate spacing at higher temperatures.

Table X is a record of a test conducted by mounting a similar gage on a second calibration bar. A Time/Temperature Chart of the test is shown (Figure 13). Run # 221 charts the initial (no load) heat cycle. Approximately eight hours of testing followed (Run # 222).

Run # 219 indicates the zero offset obtained from a strain gage with an alternate heat treatment. Tables XI and XII list the test record of a strain gage mounted on a similar fixture. The fixture was fabricated from J1650, a "Superalloy" used for gas turbine blades. The Time/Temperature Chart is shown in Figure 14. Approximately twenty hours of test results are graphically presented in Runs # 224, # 225, # 226. Results of numerous gage factor vs. temperature tests were plotted (Figure 15).

Two gages were mounted in a back-to-back (bending) configuration on the test specimen (Figure 4). The T-C curves of each gage were compared (Runs # 144, # 145). Load and no load runs were conducted, using different pin diameters in the fixture. Run # 146 was conducted using 1/4" pins, while Run # 147 was conducted with 3/16" pins. The results are in agreement with data from Figure 15.

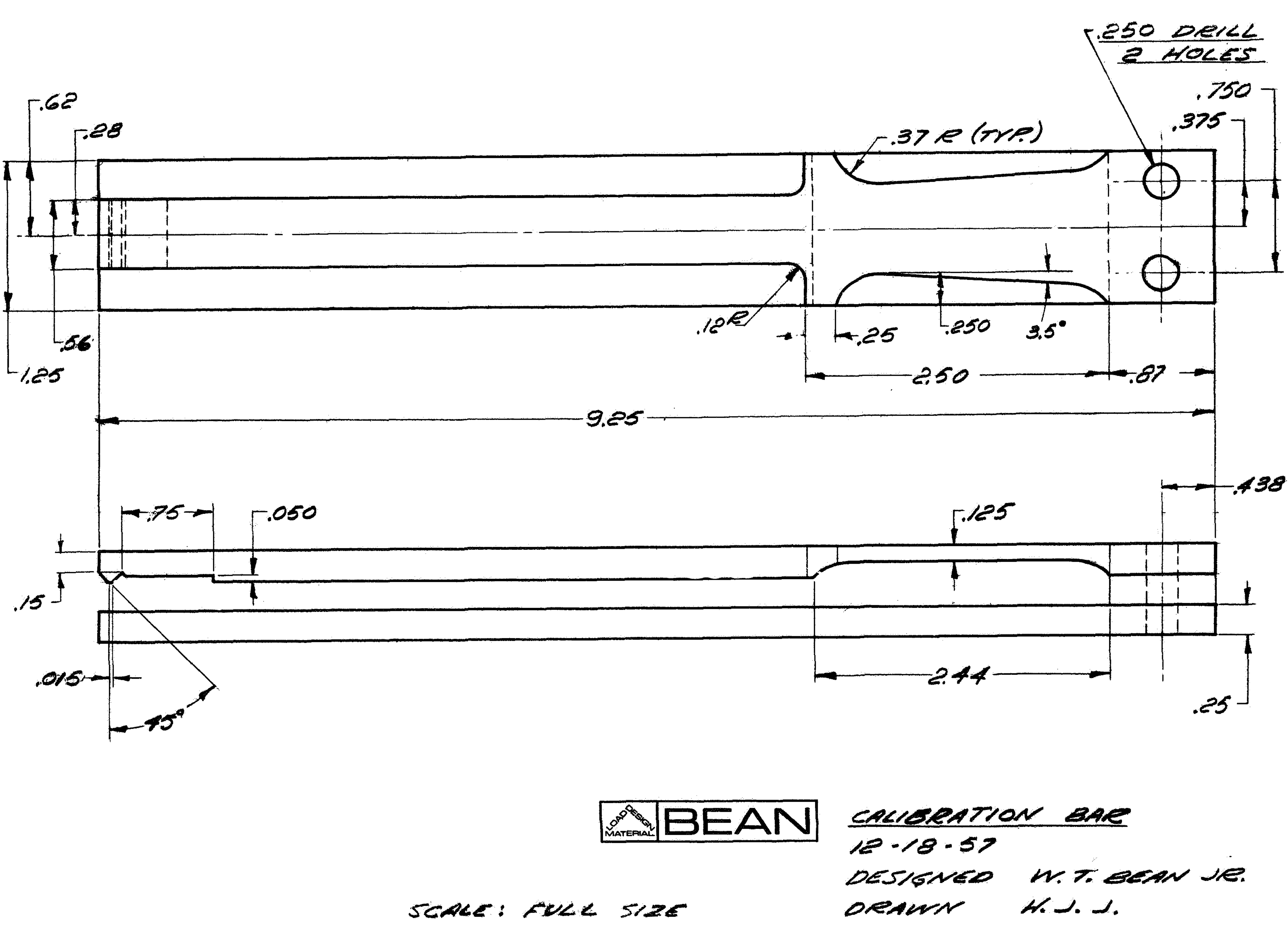

.250 DRILL
2 HOLES
.750
.375
.62
.28
.37 R (TYP.)
.12R
.25
.250
3.5°
.56
1.25
2.50
.87
9.25
.438
.75
.050
.125
.15
.015
45°
2.44
.25
BEAN
CALIBRATION BAR
12-18-57
DESIGNED W. T. BEAN JR.
DRAWN H. J. J.
SCALE: FULL SIZE

FIGURE 12.

Table IX

<u>Gage Factor vs Temperature</u>

First Cycle Point by Point Data*
(Prior to Runs #200 & #201)

Test Temperature	Apparent Strain	Load Strain	Percent G.F./100°F
100°F	0 $\mu\varepsilon$	586 $\mu\varepsilon$	100.0
250	-711	555	94.7
400	-970	525	89.6
450	-981	---	---
600	-724	492	84.0
786	0	---	---
800	42	465	79.4
975	1045	451	77.0
800	46	463	79.0
600	-758	492	84.0
500	-961	---	---
400	-1012	525	89.6
250	-737	---	---
100	-16	586	100.0

*17-4 PH Test Fixture, 1/4" Section
Alloy #13/#3

ALLOY #13/#3/HA RUN NO. 200

ADHESIVE H-1 CURE 1HR @ 600°F

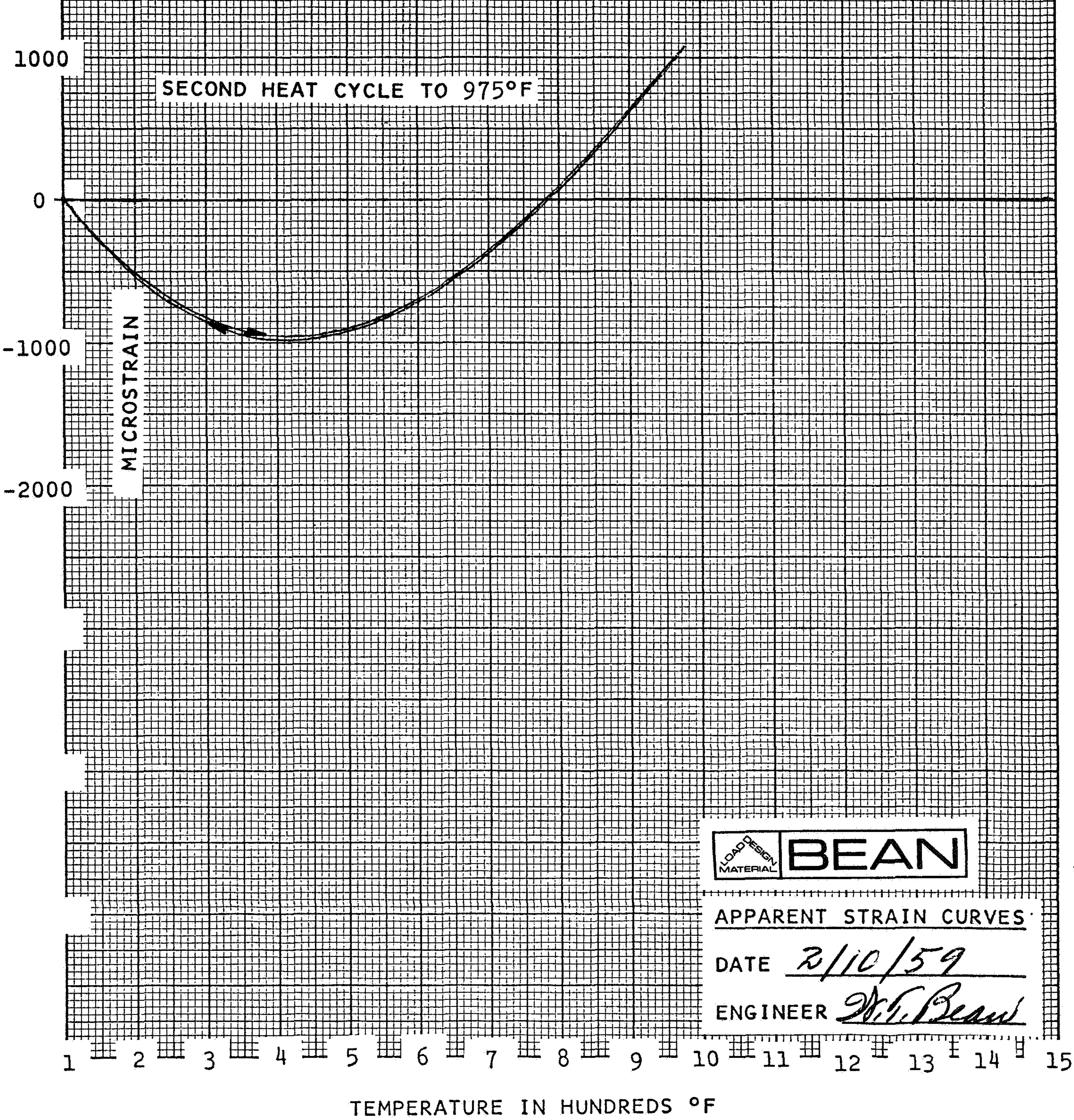
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL 17-4PH (1/4")

HEATING & COOLING RATE 20/10°F/MIN.

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



LOAD DESIGN MATERIAL BEAN

APPARENT STRAIN CURVES

DATE 2/10/59

ENGINEER W.T. Bean

ALLOY #13/#3/HA RUN NO. 201

ADHESIVE H-1 CURE 1HR @ 600°F

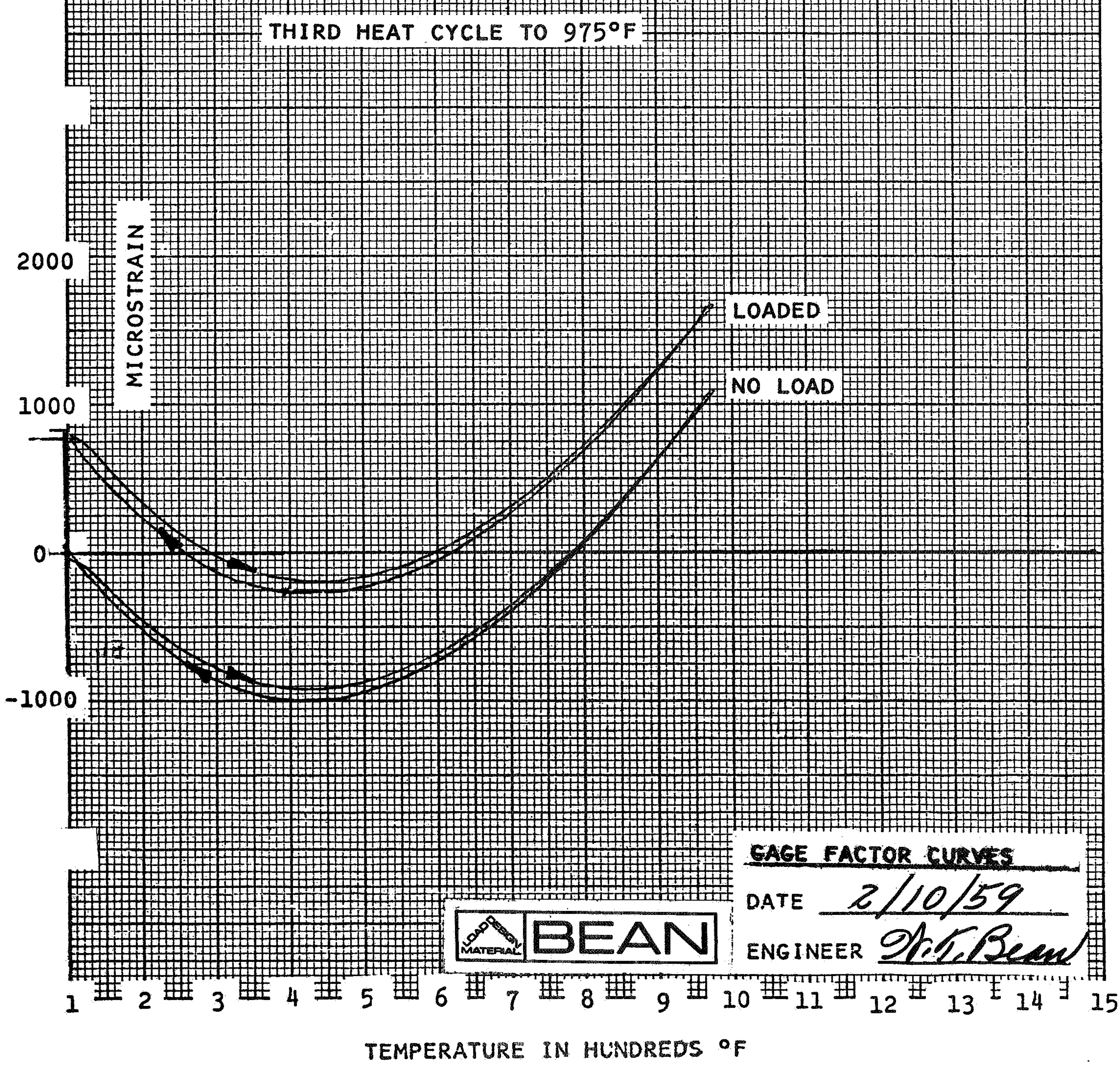
CLAMP PRESSURE No POST CURE No

SPECIMEN MATERIAL 17-4PH (1/4")

HEATING & COOLING RATE 35/25°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



GAGE FACTOR CURVES

DATE 2/10/59

ENGINEER N.T. Bean

BEAN

Table X

RECORD OF TEST ON 17-4 PH FIXTURE

RUN NO. 221, 222

TEST EVENT	DESCRIPTION OF TEST	LAPSED TIME
0-1	Heat (100°F to 950°F) no load	1:10
1-2	Cool (950°F to 100°F) in air	2:05
a-b	Load (+870με) 100°F	2:06
b-c	Heat (100°F to 820°F) loaded	3:06
c-b	Cool (820°F to 100°F) loaded	4:11
b-d	Load (+1620με) 100°F	4:12
d-e	Heat (100°F to 700°F) loaded	4:52
e-d	Cool (700°F to 100°F) loaded	5:37
d-a	Unload at 100°F	5:38
a-f	Load (-2100με) 100°F	5:39
f-g	Heat (100°F to 700°F) loaded	6:15
g-f	Cool (700°F to 100°F) loaded	7:00
f-a	Unload at 100°F, standby	7:15
a-h	Heat (100°F to 950°F) no load	8:15
h-i	Cool (950°F to 875°F) no load	8:37
i-j	Load (+870με) 875°F	8:38
j-k	Cool (875°F to 825°F) loaded	8:40
k-l	Unload at 825°F	8:42
l-m	Cool (825°F to 790°F) no load	8:44
m-n	Load (+1620με) 790°F	8:45
n-o	Cool (790°F to 720°F) loaded	8:50
o-p	Load (-2100με) 720°F	8:51
p-q	Heat (720°F to 775°F) loaded	9:10
q-r	Unload at 775°F	9:11
r-s	Cool (775°F to 100°F) no load	10:00 hrs
a-s	Zero Offset (-30με) in 7:55 hrs	

BEAN


TIME/TEMPERATURE CHART
RUN NO. 221, 222
TEMPERATURE IN HUNDREDS °F
LAPSED TIME, HRS
0
1
2
3
4
5
6
7
8
9
10
0
Start
1
a - b
2
c
b - d
e
d - a
a - f
g
f
f - a
h
i - j
k - l
m - n
q - r
o - p
s

FIGURE 13

ALLOY #13/#3/HB RUN NO. 221

ADHESIVE H-1 CURE 1HR @ 600°F

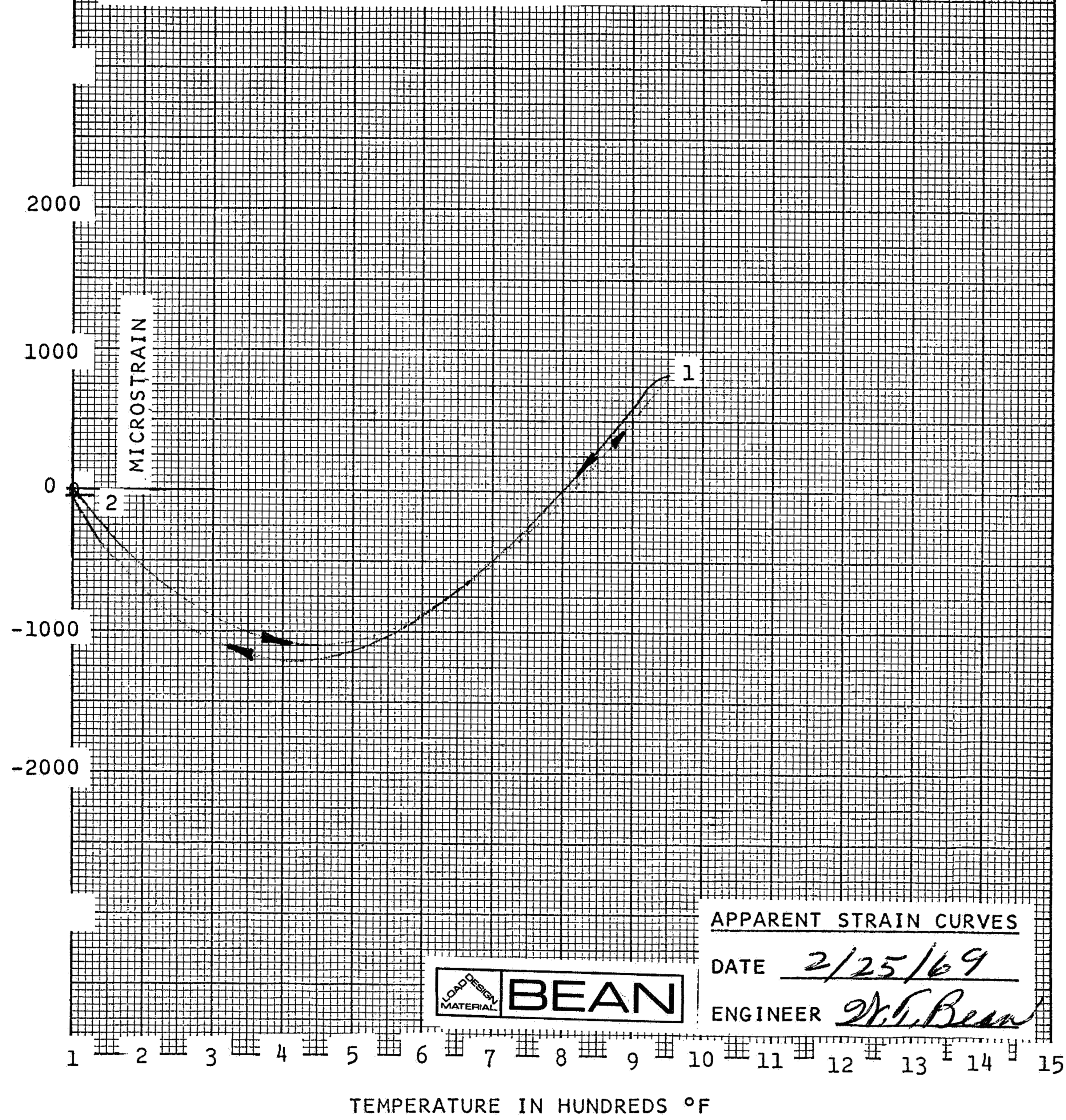
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL 17-4PH (1/8")

HEATING & COOLING RATE 10/20°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



APPARENT STRAIN CURVES

DATE 2/25/69

ENGINEER W.T. Bean

LOAD DESIGN MATERIAL BEAN

ALLOY #13/#3/HB RUN NO. 222

ADHESIVE H-1 CURE 1 HR @ 600°F

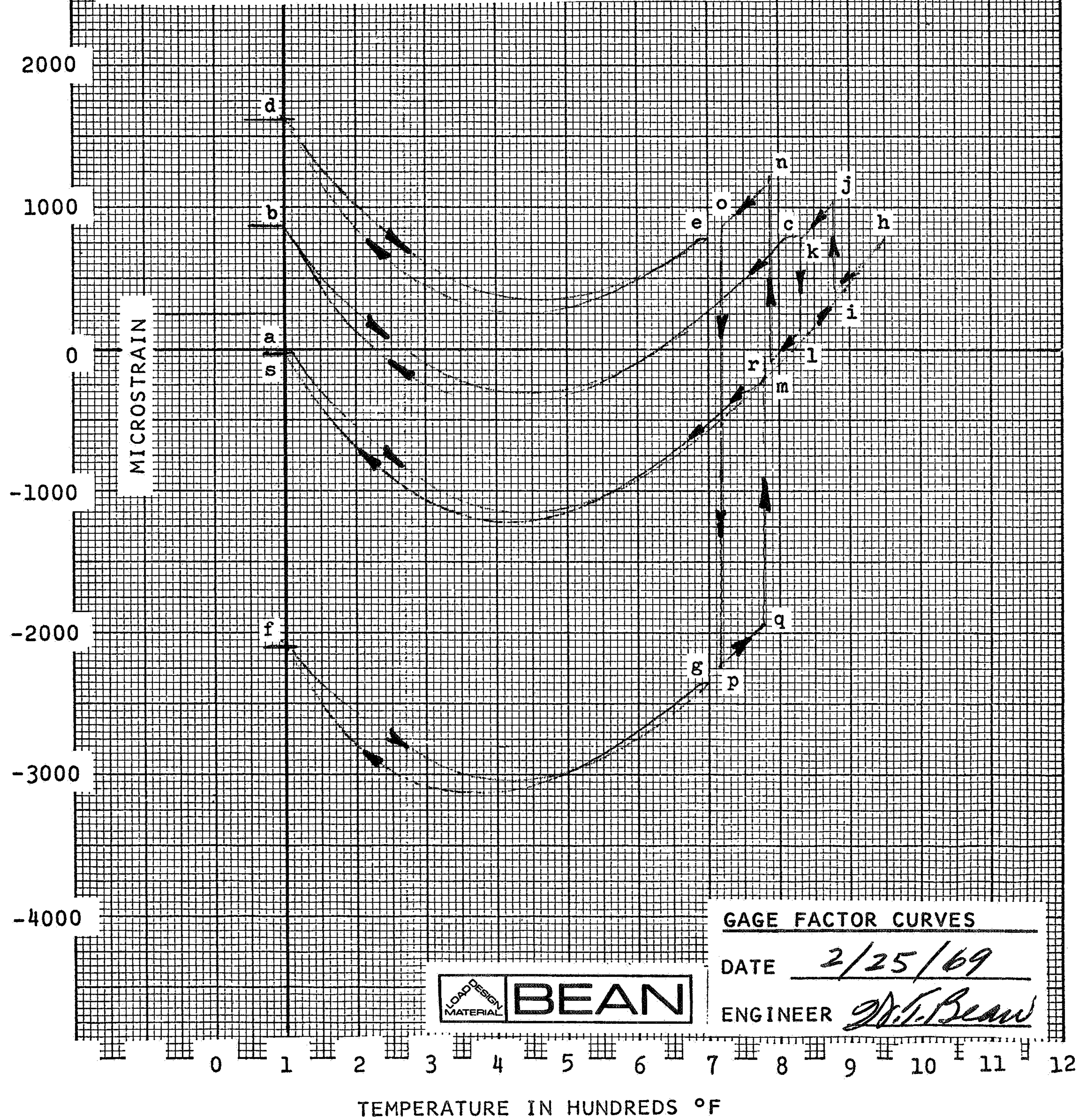
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL 17-4 PH (1/8")

HEATING & COOLING RATE 10/20°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



GAGE FACTOR CURVES

DATE 2/25/69

ENGINEER W.T. Bean

BEAN LOAD DESIGN MATERIAL

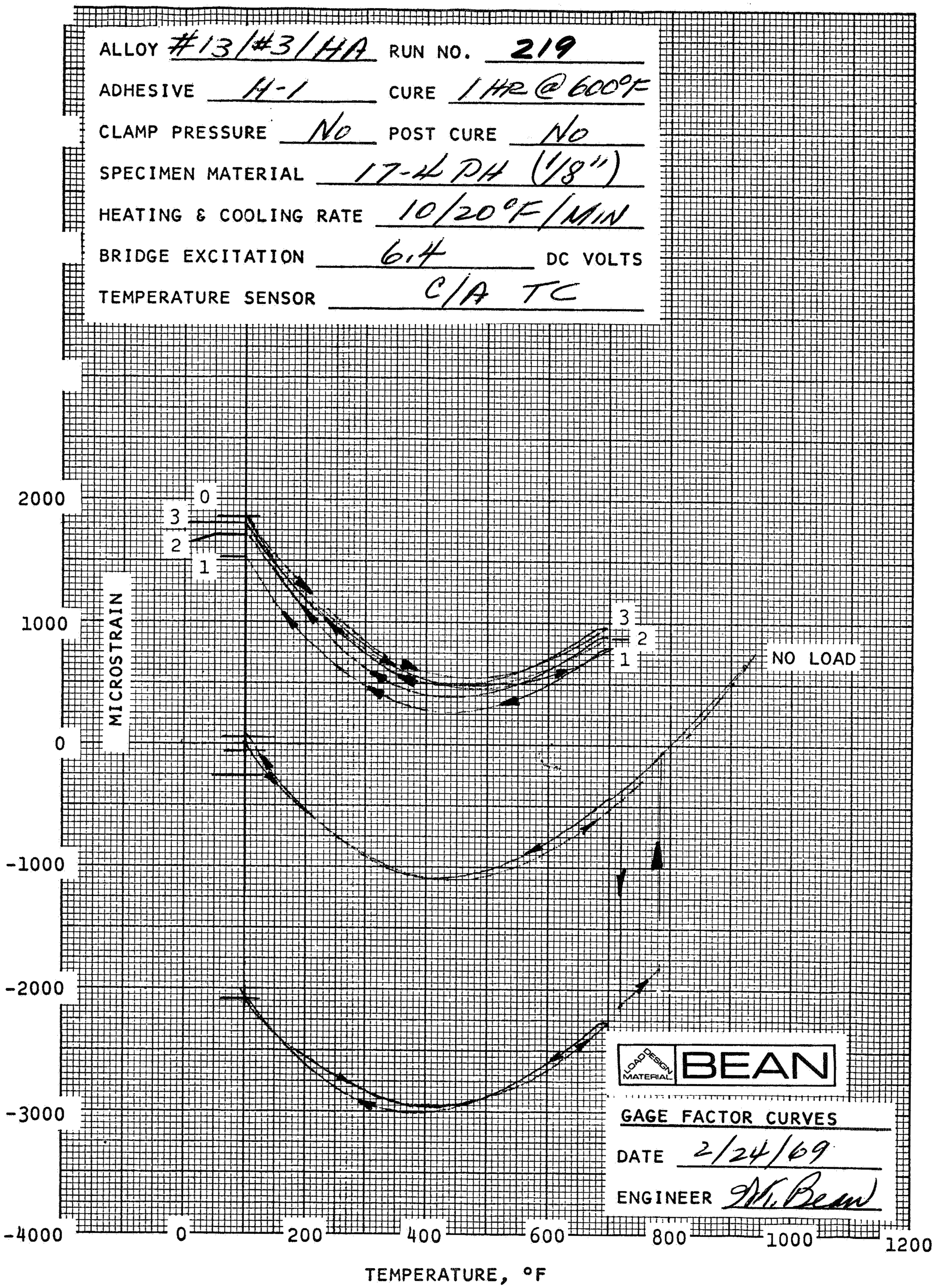

ALLOY #13/#3/HA
RUN NO. 219
ADHESIVE H-1
CURE 1 HR @ 600°F
CLAMP PRESSURE No
POST CURE No
SPECIMEN MATERIAL 17-4 PH (1/8")
HEATING & COOLING RATE 10/20°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
MICROSTRAIN
2000
1000
0
-1000
-2000
-3000
-4000
0
3
2
1
3
2
1
NO LOAD
0
200
400
600
800
1000
1200
TEMPERATURE, °F
LOAD DESIGN MATERIAL
BEAN
GAGE FACTOR CURVES
DATE 2/24/69
ENGINEER W. Bean

Table XI

RECORD OF TEST ON J-1650 FIXTURE

RUN NO. 224, 225

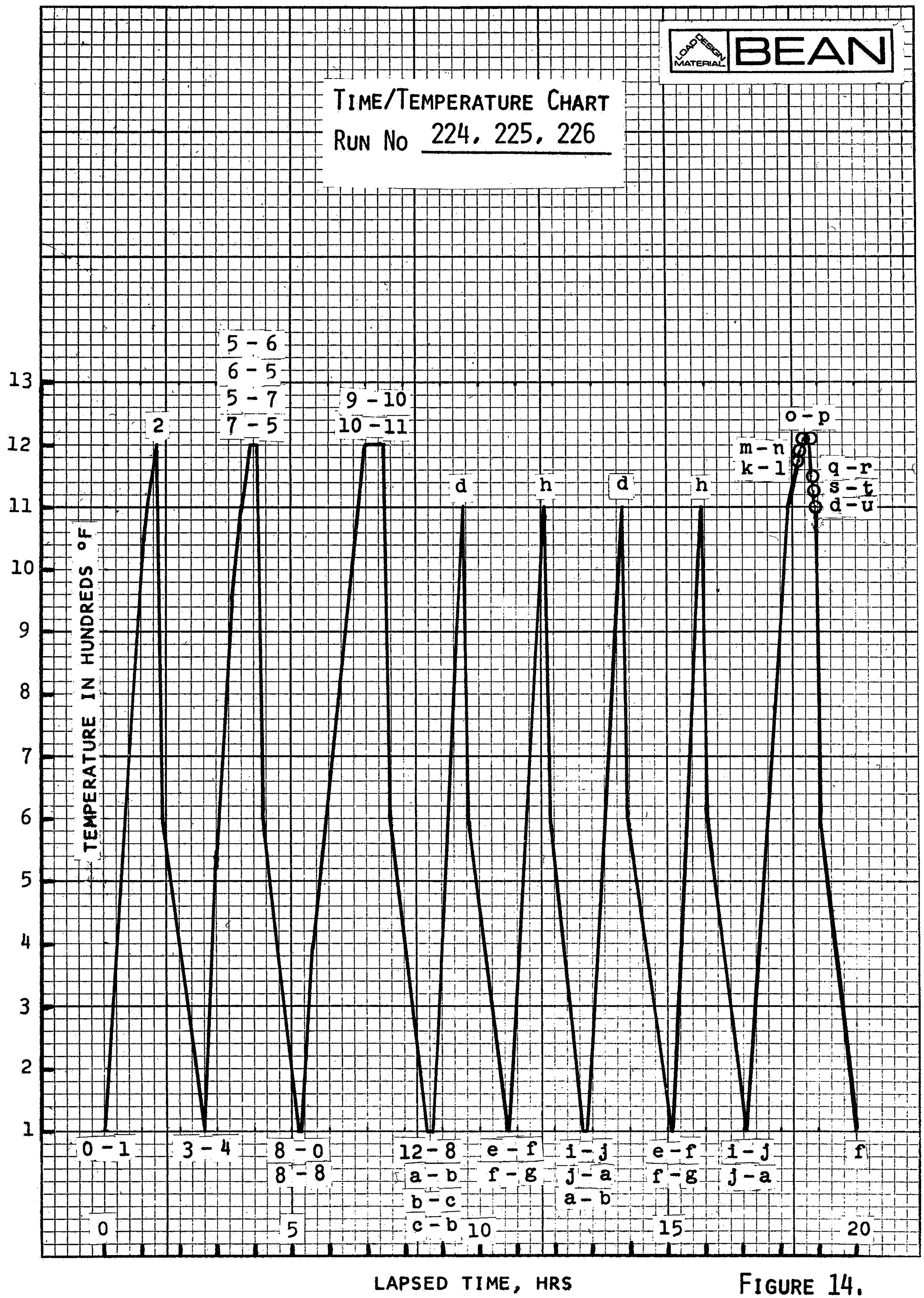
TEST EVENT	DESCRIPTION OF TEST	LAPSED TIME
0-1	Load (+960$\mu\varepsilon$) 100°F	0:01
1-2	Heat (100°F to 1200°F) loaded	1:25
2-3	Cool (1200°F to 100°F) loaded	2:40
3-4	Unload at 100°F	2:41
4-5	Heat (100°F to 1200°F) no load	3:56
5-6	Load (+960$\mu\varepsilon$) 1200°F	3:57
6-5	Unload at 1200°F	3:58
5-7	Load (-815$\mu\varepsilon$) 1200°F	3:59
7-5	Unload at 1200°F	4:00
5-8	Cool (1200°F to 100°F) no load	5:10
8-0	Zero Offset (-700$\mu\varepsilon$)	
8-8	New Chart (New Zero)	5:15
8-9	Heat (100°F to 1200°F) no load	7:00
9-10	Drift Check at 1200°F (15 min)	7:15
10-11	Drift Check at 1200°F (15 min)	7:30
11-12	Cool (1200°F to 100°F) no load	8:35 hrs
12- 8	Zero Offset (+50$\mu\varepsilon$)	

Table XII

RECORD OF TEST ON J-1650 FIXTURE

RUN NO. 226

TEST EVENT	DESCRIPTION OF TEST	LAPSED TIME
a	New chart (new Zero)	8:40
a-b	Load (+990με) 100°F	8:41
b-c	Load (-865με) 100°F	8:43
c-b	Load (+990με) 100°F	8:45
b-d	Heat (100°F to 1100°F) loaded	9:35
d-e	Cool (1100°F to 100°F) loaded	10:45
e-f	Unload "T" at 100°F	10:46
f-g	Load (-865με) 100°F	10:47
g-h	Heat (100°F to 1100°F) loaded	11:47
h-i	Cool (1100°F to 100°F) loaded	12:47
i-j	Unload "C" at 100°F	12:48
j-a	Reset Zero	12:49
a-b	Load (+990με) 100°F	12:50
b-d	Heat (100°F to 1100°F) loaded	13:50
d-e	Cool (1100°F to 100°F) loaded	15:05
e-f	Unload at 100°F "T" checks	15:06
f-g	Load (-865με) 100°F	15:07
g-h	Heat (100°F to 1100°F) loaded	15:57
h-i	Cool (1100°F to 100°F) loaded	17:02
i-j	Unload at 100°F "C" checks	17:03
j-a	Reset Zero	17:04
a-k	Heat (100°F to 1175°F) no load	18:29
k-l	Load (-815με) 1175°F	18:30
l-m	Heat (1175°F to 1190°F) loaded	18:33
m-n	Unload at 1190°F	18:34
n-o	Heat (1190°F to 1210°F) no load	18:38
o-p	Load (+960με) 1210°F	18:39
p-q	Cool (1210°F to 1150°F) loaded	18:49
q-r	Load (+960με to -815με) 1150°F	18:50
r-s	Cool (1150°F to 1125°F) loaded	18:52
s-t	Load (-815με to +960με) 1125°F	18:53
t-d	Cool (1125°F to 1100°F) loaded	18:55
d-u	Unload at 1100°F	18:56
u-f	Cool (1100°F to 100°F)	19:58 hrs



BEAN
LOAD DESIGN MATERIAL
TIME/TEMPERATURE CHART
RUN NO 224, 225, 226
TEMPERATURE IN HUNDREDS °F
13
12
11
10
9
8
7
6
5
4
3
2
1
2
5 - 6
6 - 5
5 - 7
7 - 5
9 - 10
10 - 11
d
h
d
h
o - p
m - n
k - l
q - r
s - t
d - u
0 - 1
3 - 4
8 - 0
8 - 8
12 - 8
a - b
b - c
c - b
e - f
f - g
i - j
j - a
a - b
e - f
f - g
i - j
j - a
f
0
5
10
15
20
LAPSED TIME, HRS

FIGURE 14.

ALLOY #13/#3/HB RUN NO. 224

ADHESIVE H-1 CURE 1HR @600°F

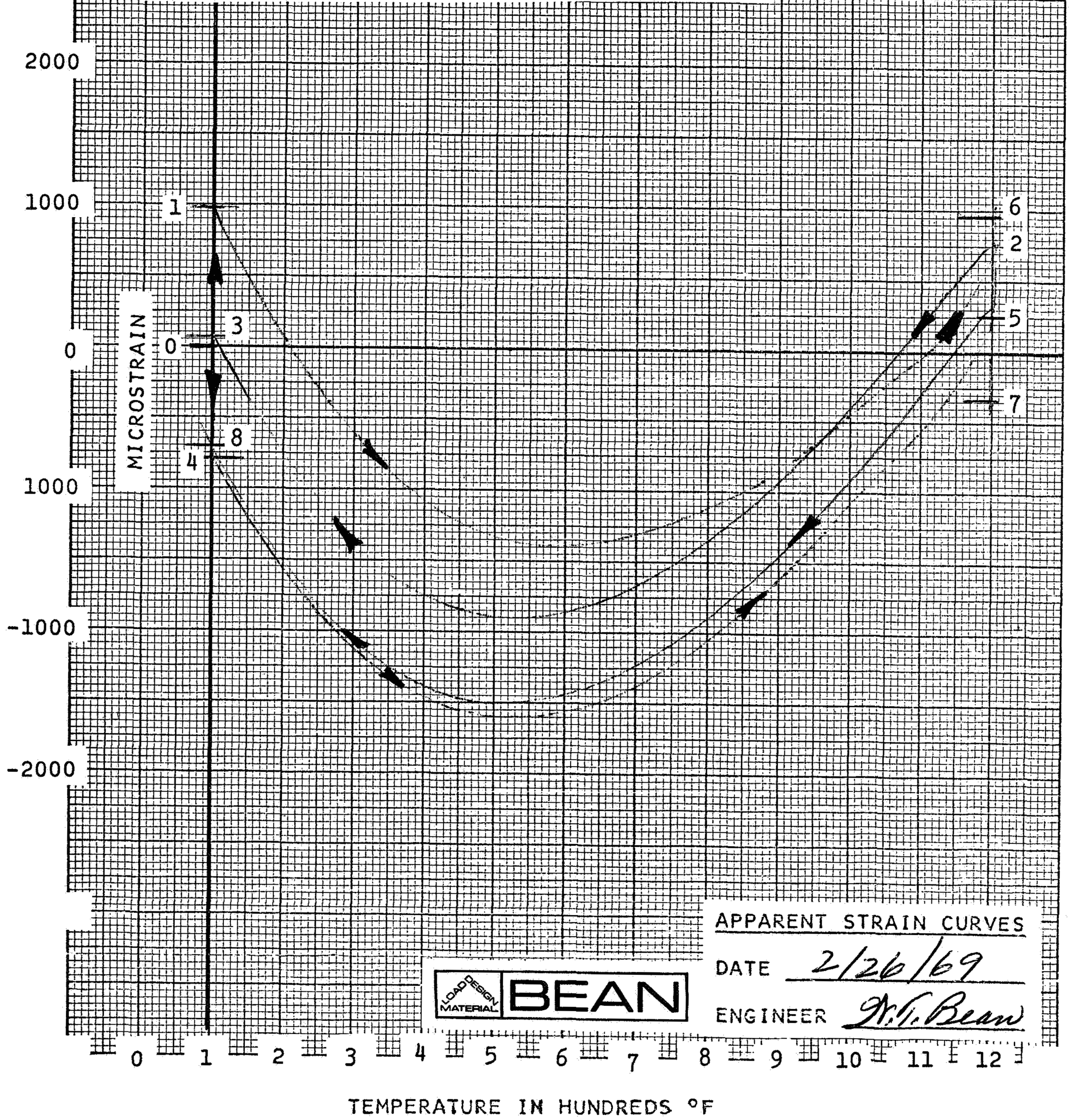
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL J-1650 (1/8")

HEATING & COOLING RATE 20/60°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



APPARENT STRAIN CURVES

DATE 2/26/69

BEAN LOAD DESIGN MATERIAL

ENGINEER W.T. Bean

ALLOY #13/#3/HB RUN NO. 225

ADHESIVE H-1 CURE 1HR @ 600°F

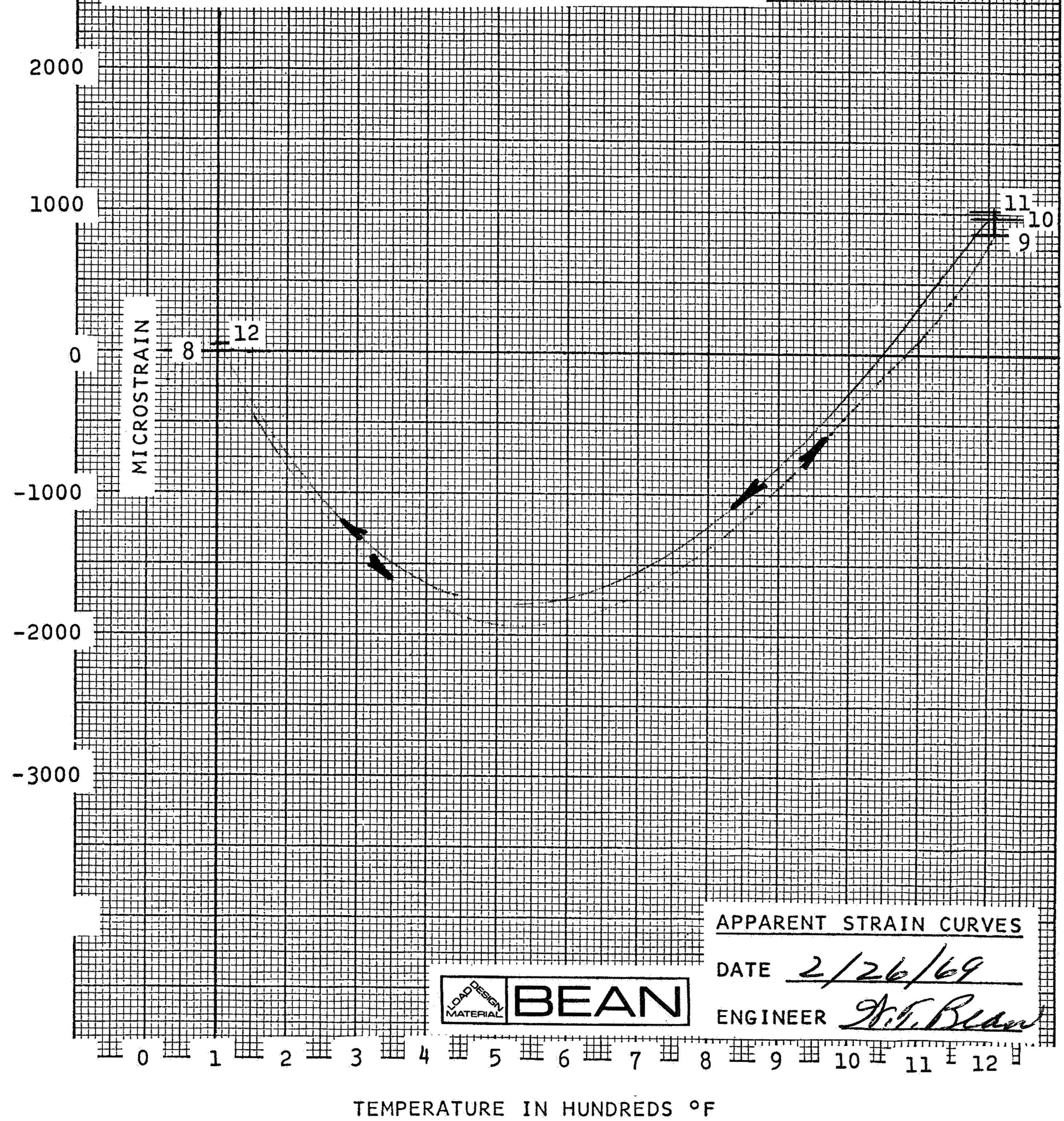
CLAMP PRESSURE No POST CURE No

SPECIMEN MATERIAL J-1650 (1/8")

HEATING & COOLING RATE 20/60°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



APPARENT STRAIN CURVES

DATE 2/26/69

ENGINEER W.T. Bean

LOAD DESIGN MATERIAL BEAN

ALLOY #13/#3/HB RUN NO. 226

ADHESIVE H-1 CURE 1HR @ 600°F

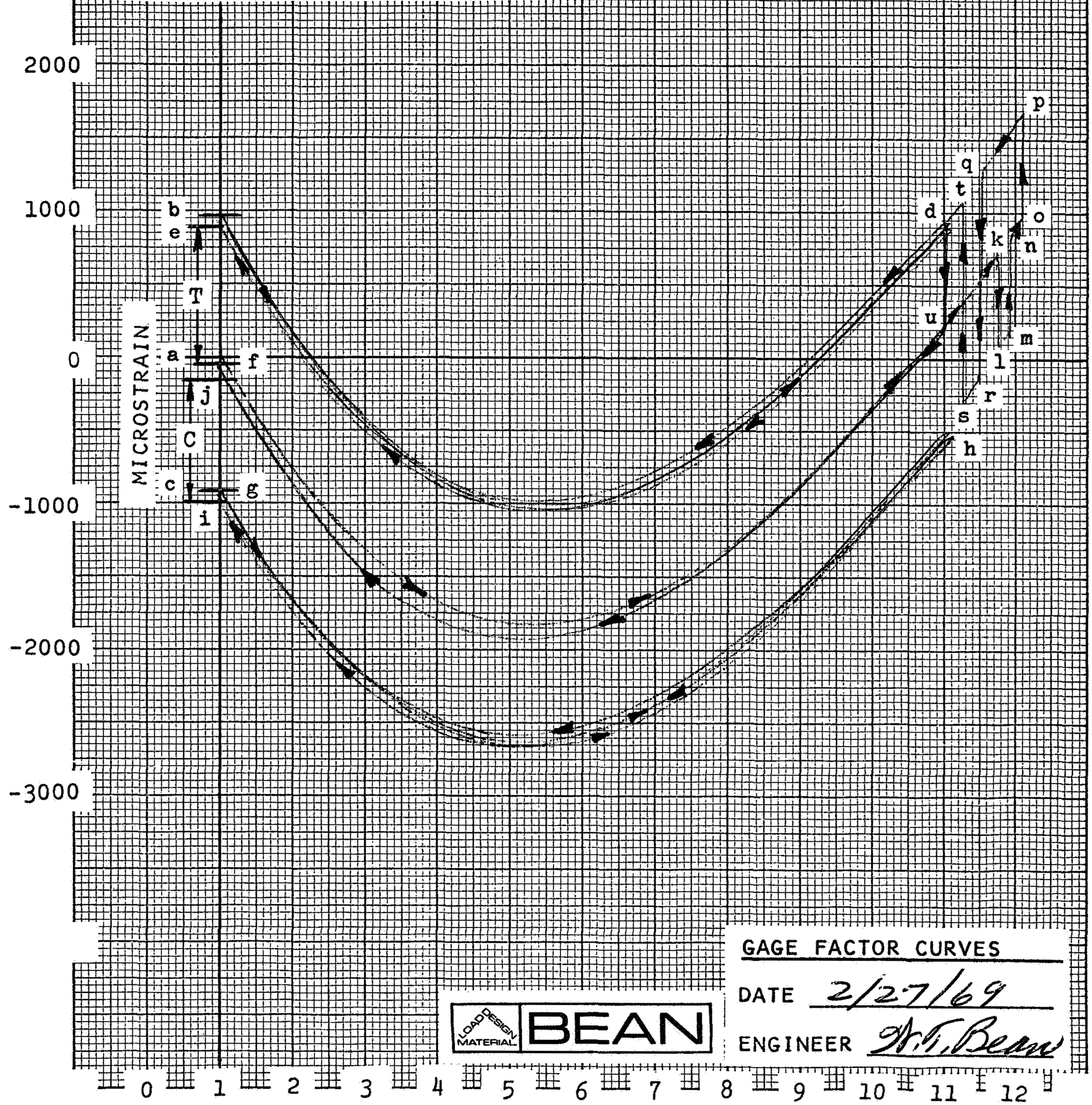
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL J-1650 (1/8")

HEATING & COOLING RATE 20/60°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC



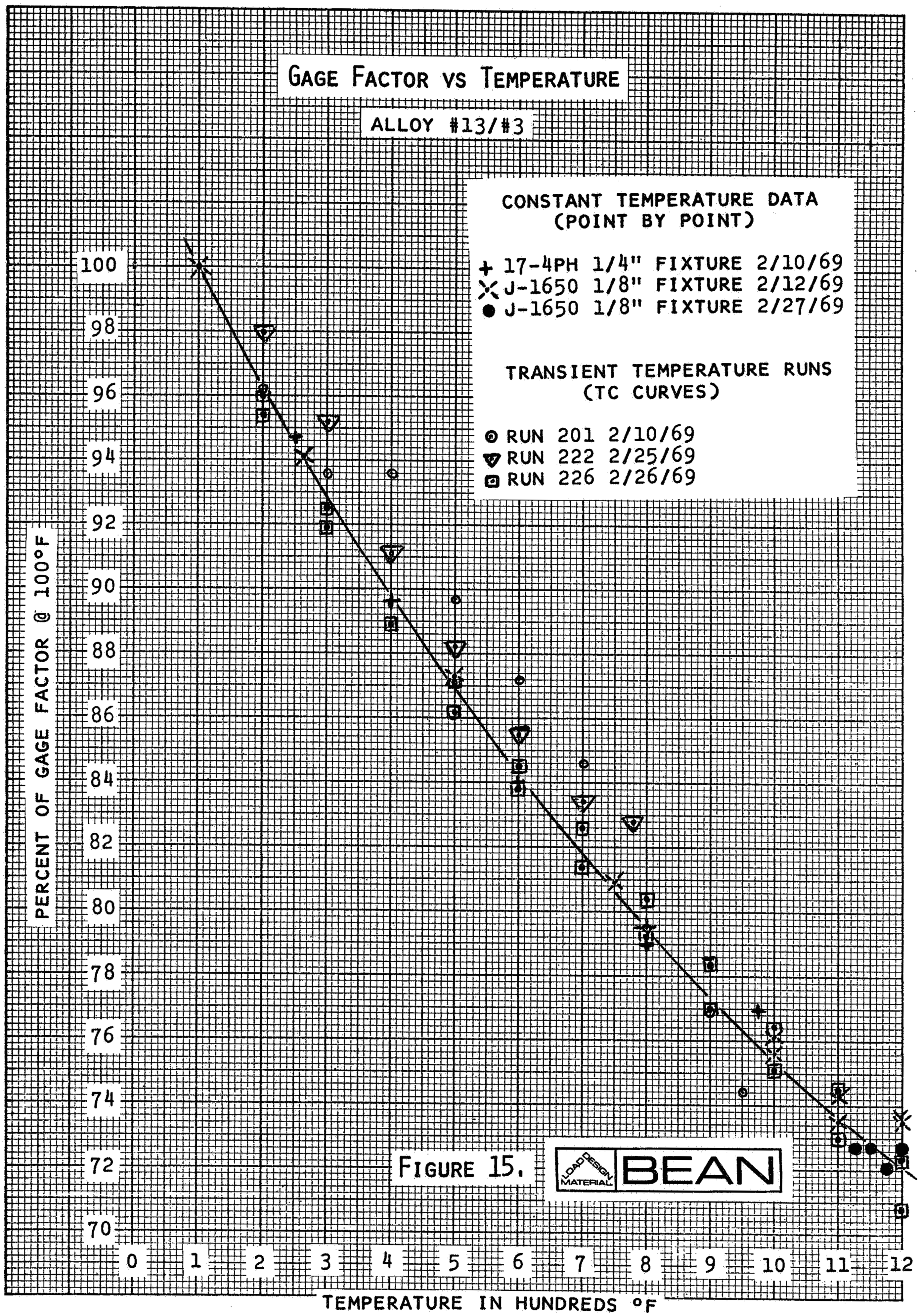
TEMPERATURE IN HUNDREDS °F

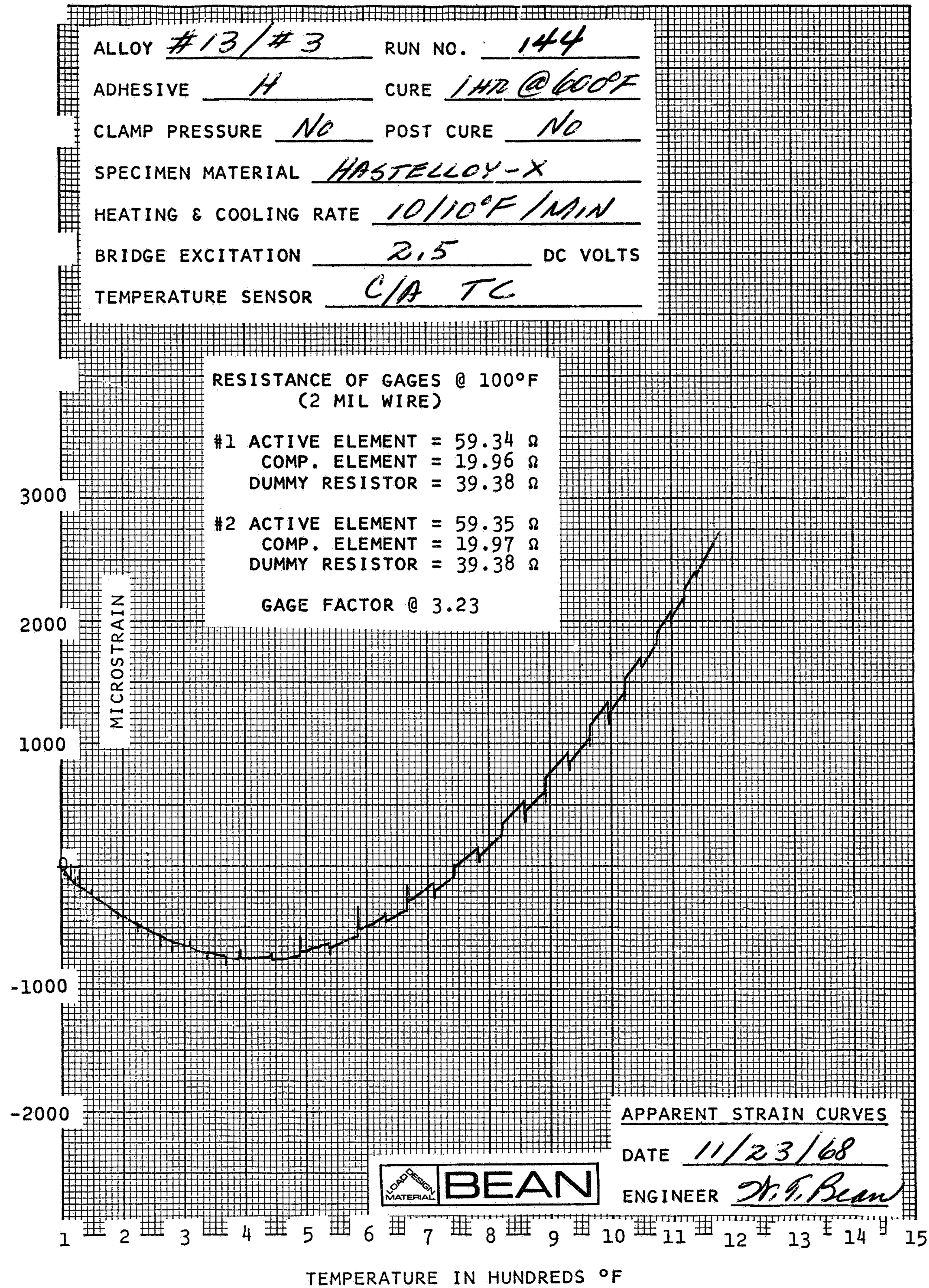
GAGE FACTOR CURVES

DATE 2/27/69

ENGINEER W.T. Bean

BEAN


GAGE FACTOR VS TEMPERATURE
ALLOY #13/#3
CONSTANT TEMPERATURE DATA
(POINT BY POINT)
17-4PH 1/4" FIXTURE 2/10/69
J-1650 1/8" FIXTURE 2/12/69
J-1650 1/8" FIXTURE 2/27/69
TRANSIENT TEMPERATURE RUNS
(TC CURVES)
RUN 201 2/10/69
RUN 222 2/25/69
RUN 226 2/26/69
PERCENT OF GAGE FACTOR @ 100°F
100
98
96
94
92
90
88
86
84
82
80
78
76
74
72
70
0
1
2
3
4
5
6
7
8
9
10
11
12
TEMPERATURE IN HUNDREDS °F
BEAN
LOAD DESIGN MATERIAL
FIGURE 15.


ALLOY #13/#3
RUN NO. 144
ADHESIVE H
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 10/10°F/MIN
BRIDGE EXCITATION 2.5 DC VOLTS
TEMPERATURE SENSOR C/A TC
RESISTANCE OF GAGES @ 100°F
(2 MIL WIRE)
#1 ACTIVE ELEMENT = 59.34 Ω
COMP. ELEMENT = 19.96 Ω
DUMMY RESISTOR = 39.38 Ω
#2 ACTIVE ELEMENT = 59.35 Ω
COMP. ELEMENT = 19.97 Ω
DUMMY RESISTOR = 39.38 Ω
GAGE FACTOR @ 3.23
MICROSTRAIN
3000
2000
1000
0
-1000
-2000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
APPARENT STRAIN CURVES
DATE 11/23/68
ENGINEER W. T. Bean
LOAD DESIGN MATERIAL BEAN

ALLOY #13/#3 RUN NO. 145

ADHESIVE H CURE 1HR @ 600°F

CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 10/10°F/MIN

BRIDGE EXCITATION 2.5 DC VOLTS

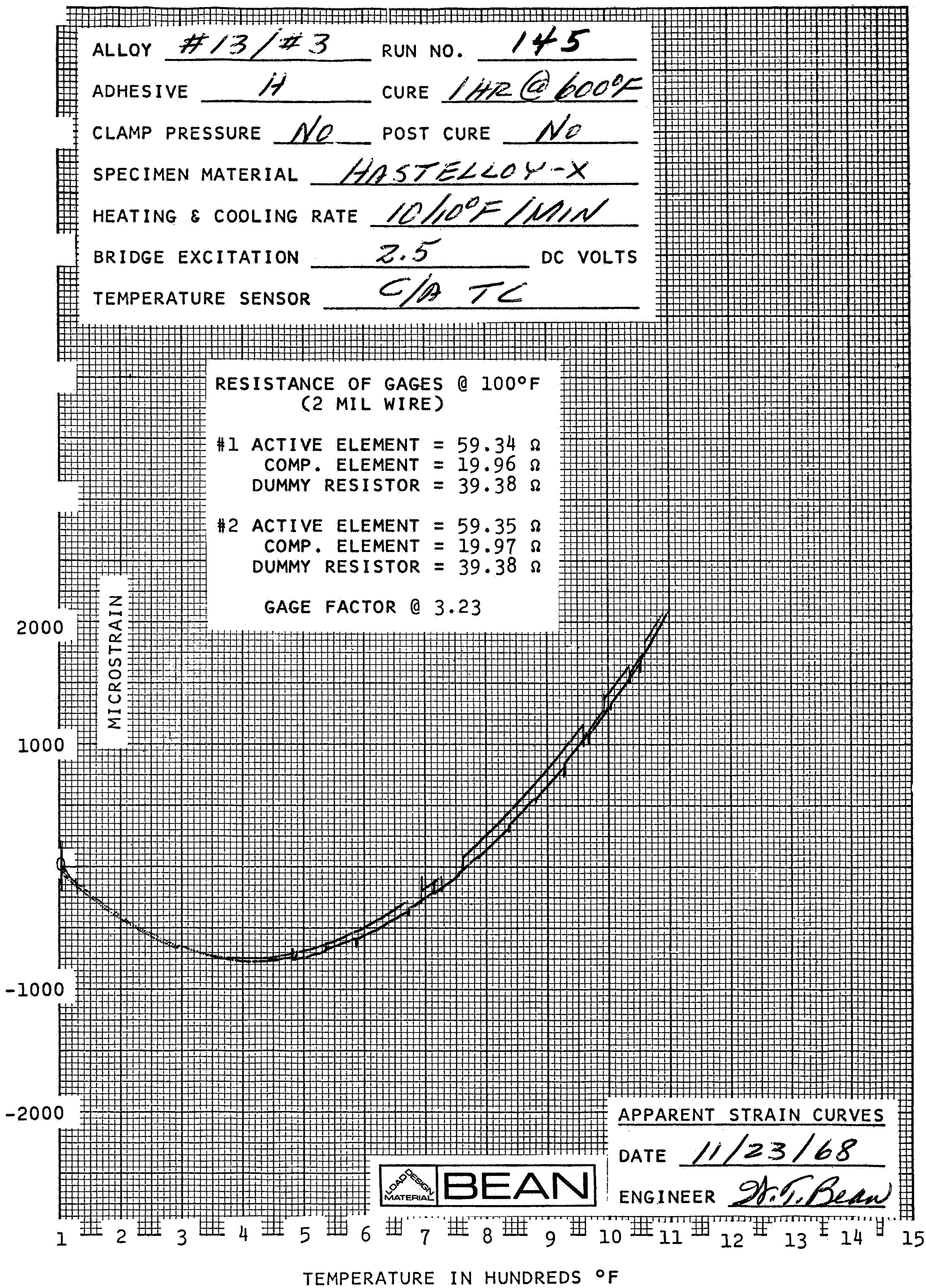
TEMPERATURE SENSOR C/A TC

RESISTANCE OF GAGES @ 100°F
(2 MIL WIRE)

#1 ACTIVE ELEMENT = 59.34 Ω
COMP. ELEMENT = 19.96 Ω
DUMMY RESISTOR = 39.38 Ω

#2 ACTIVE ELEMENT = 59.35 Ω
COMP. ELEMENT = 19.97 Ω
DUMMY RESISTOR = 39.38 Ω

GAGE FACTOR @ 3.23

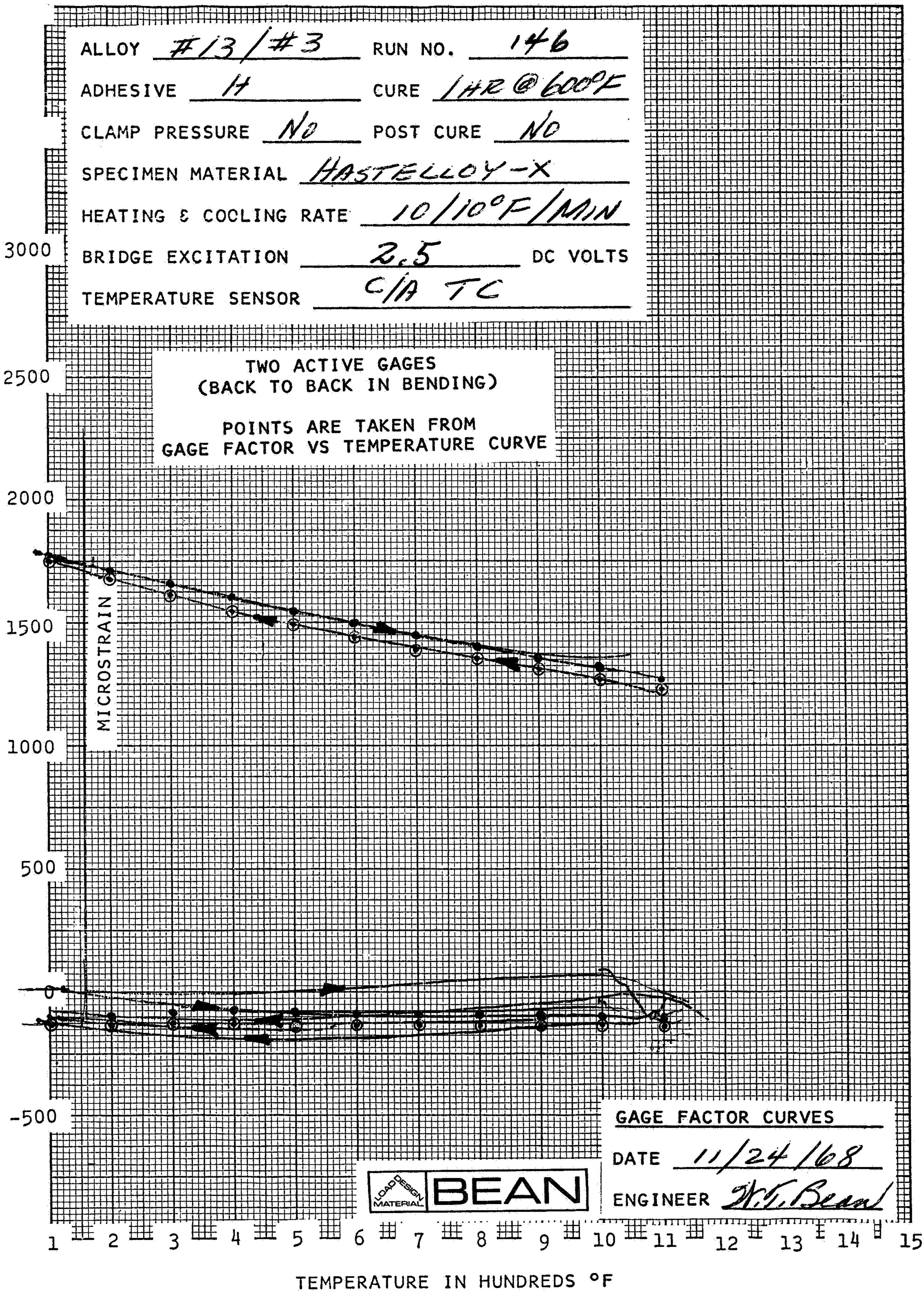


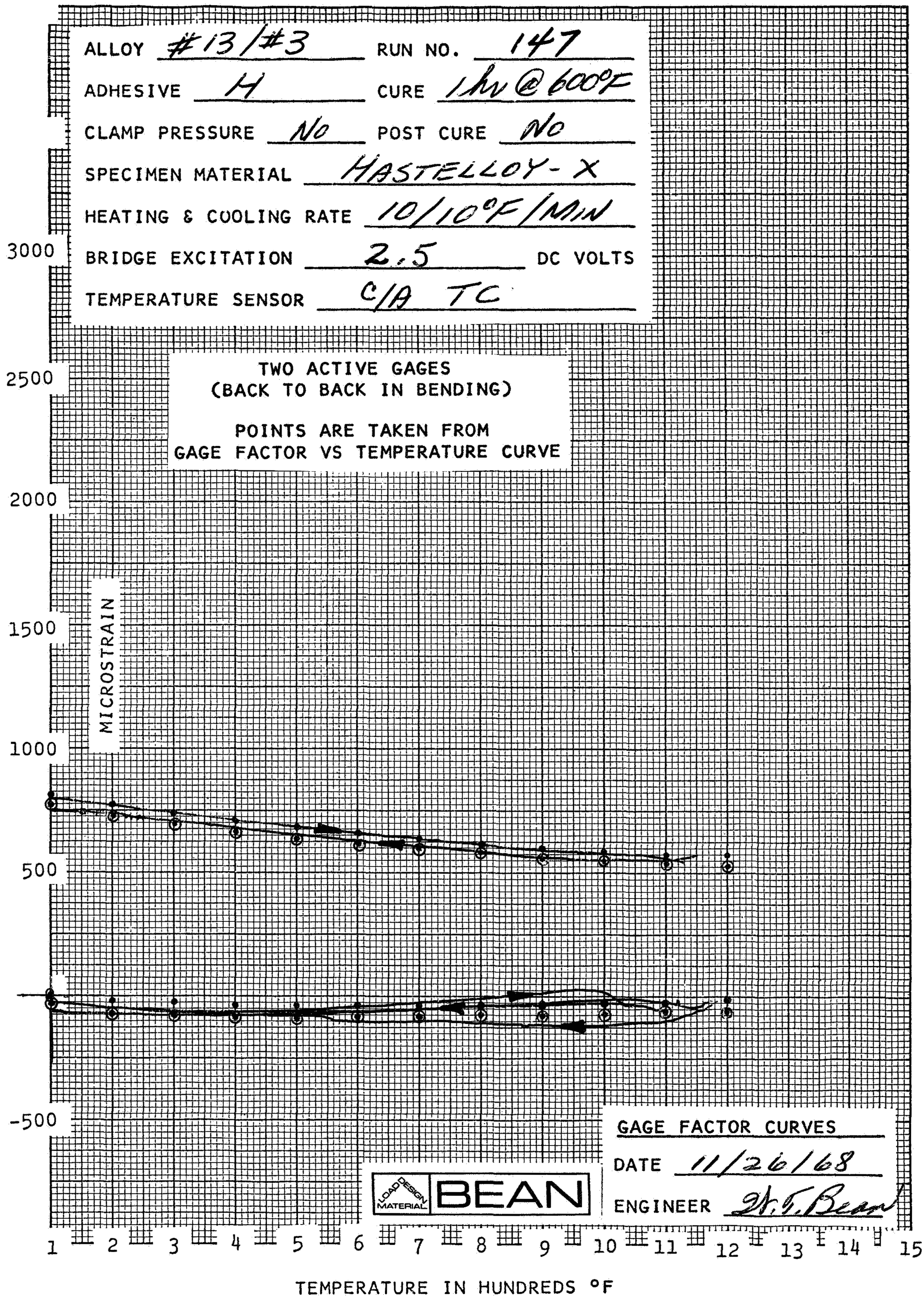
APPARENT STRAIN CURVES

DATE 11/23/68

ENGINEER W. T. Bean

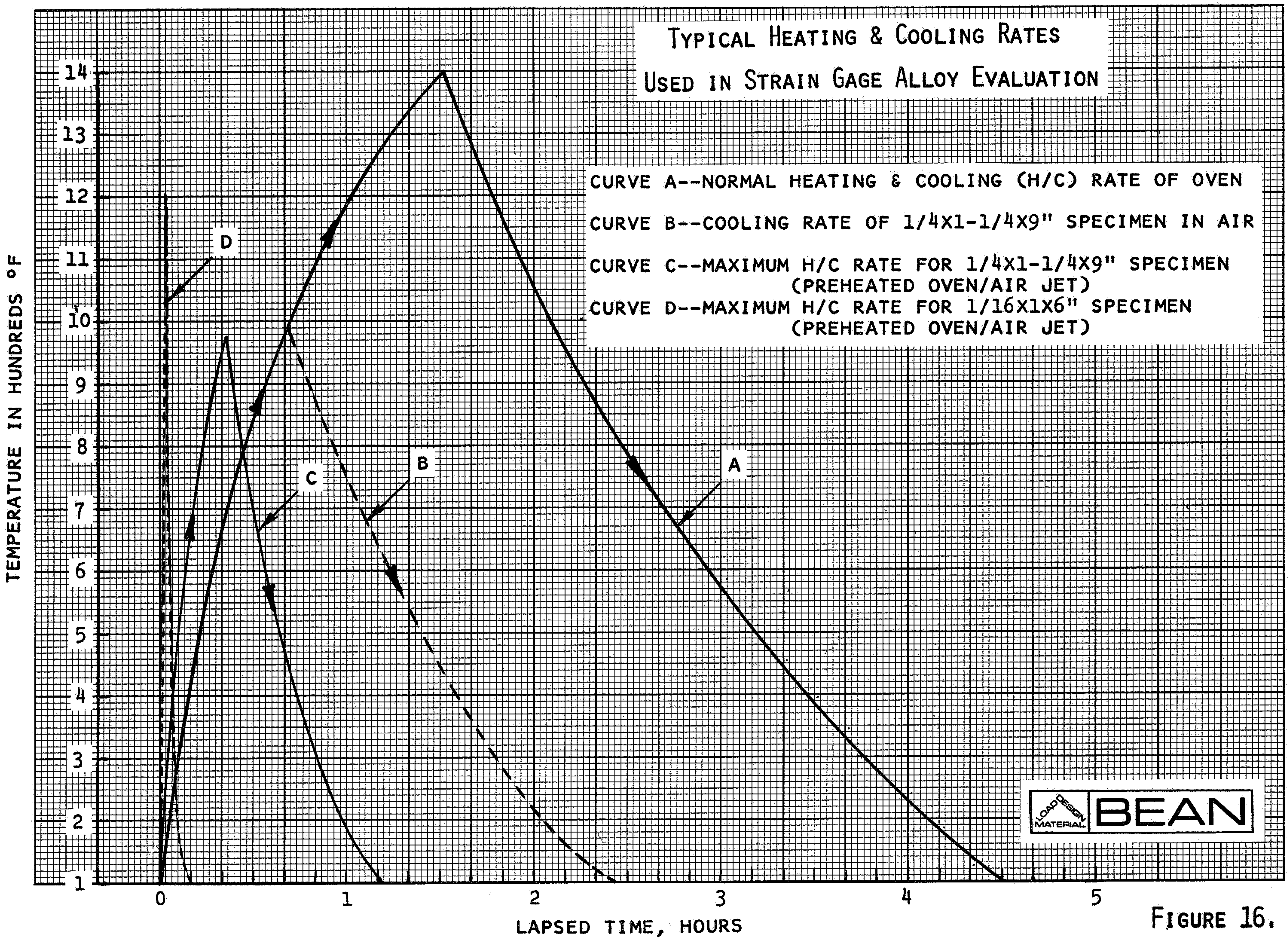
LOAD DESIGN MATERIAL BEAN


ALLOY #13/#3
RUN NO. 146
ADHESIVE H
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 10/10°F/MIN
BRIDGE EXCITATION 2.5 DC VOLTS
TEMPERATURE SENSOR C/A TC
TWO ACTIVE GAGES
(BACK TO BACK IN BENDING)
POINTS ARE TAKEN FROM
GAGE FACTOR VS TEMPERATURE CURVE
MICROSTRAIN
3000
2500
2000
1500
1000
500
0
-500
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
GAGE FACTOR CURVES
DATE 11/24/68
ENGINEER W.T. Bean
LOAD DESIGN MATERIAL BEAN


ALLOY #13/#3
RUN NO. 147
ADHESIVE H
CURE 1 hr @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 10/10°F/MIN
BRIDGE EXCITATION 2.5 DC VOLTS
TEMPERATURE SENSOR C/A TC
TWO ACTIVE GAGES
(BACK TO BACK IN BENDING)
POINTS ARE TAKEN FROM
GAGE FACTOR VS TEMPERATURE CURVE
MICROSTRAIN
3000
2500
2000
1500
1000
500
-500
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
GAGE FACTOR CURVES
DATE 11/26/68
ENGINEER W. T. Bean
LOAD DESIGN MATERIAL BEAN

Heating and Cooling Rates

The Alloy #13/#3 gage was evaluated under various heating and cooling rates (Figures 16 and 17). Heating rates up to 1000°F per minute were employed (Runs # 231 and # 232).



TYPICAL HEATING & COOLING RATES
USED IN STRAIN GAGE ALLOY EVALUATION
CURVE A--NORMAL HEATING & COOLING (H/C) RATE OF OVEN
CURVE B--COOLING RATE OF 1/4X1-1/4X9" SPECIMEN IN AIR
CURVE C--MAXIMUM H/C RATE FOR 1/4X1-1/4X9" SPECIMEN (PREHEATED OVEN/AIR JET)
CURVE D--MAXIMUM H/C RATE FOR 1/16X1X6" SPECIMEN (PREHEATED OVEN/AIR JET)
A
B
C
D
TEMPERATURE IN HUNDREDS °F
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
LAPSED TIME, HOURS
BEAN
LOAD DESIGN MATERIAL

FIGURE 16.

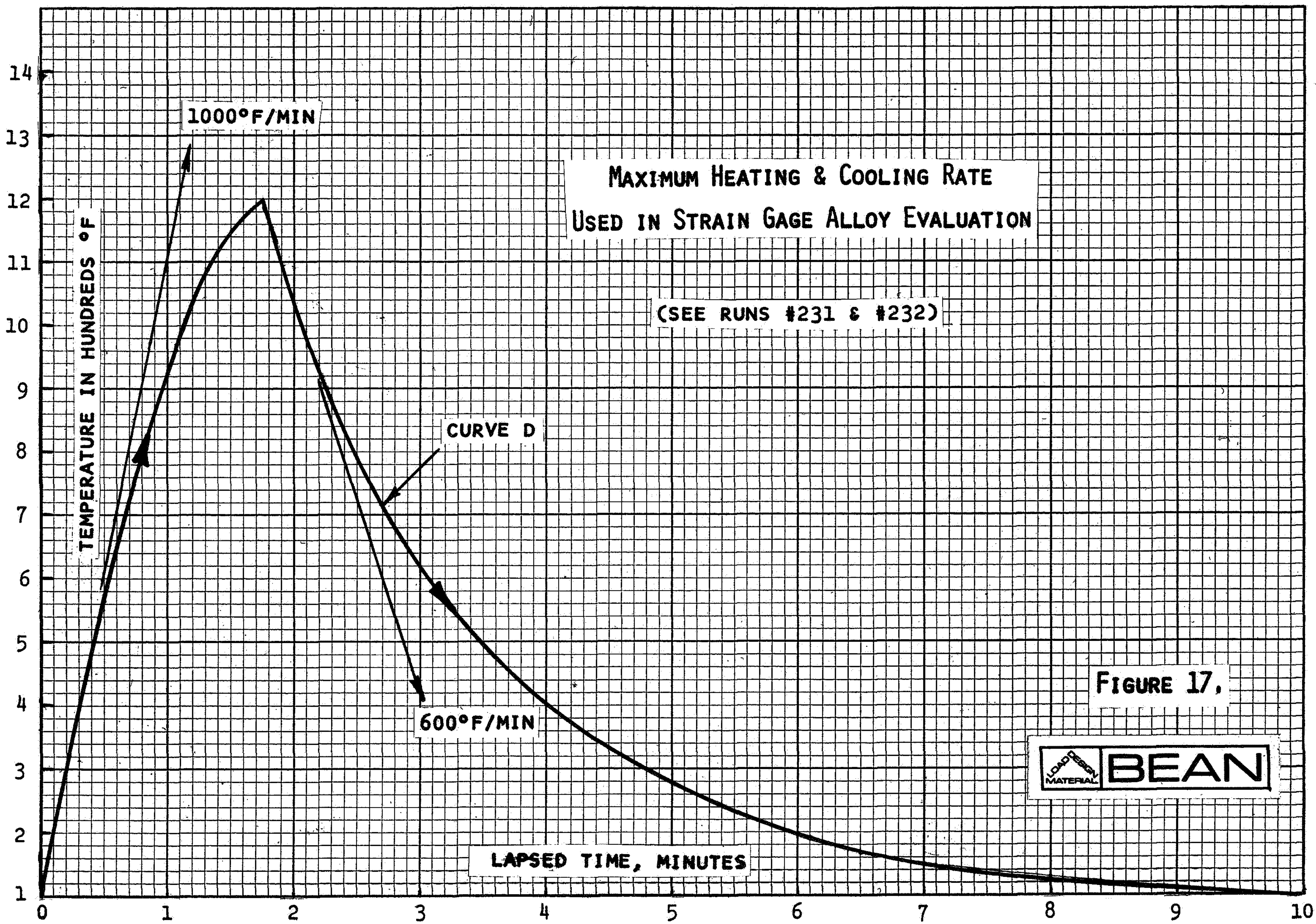
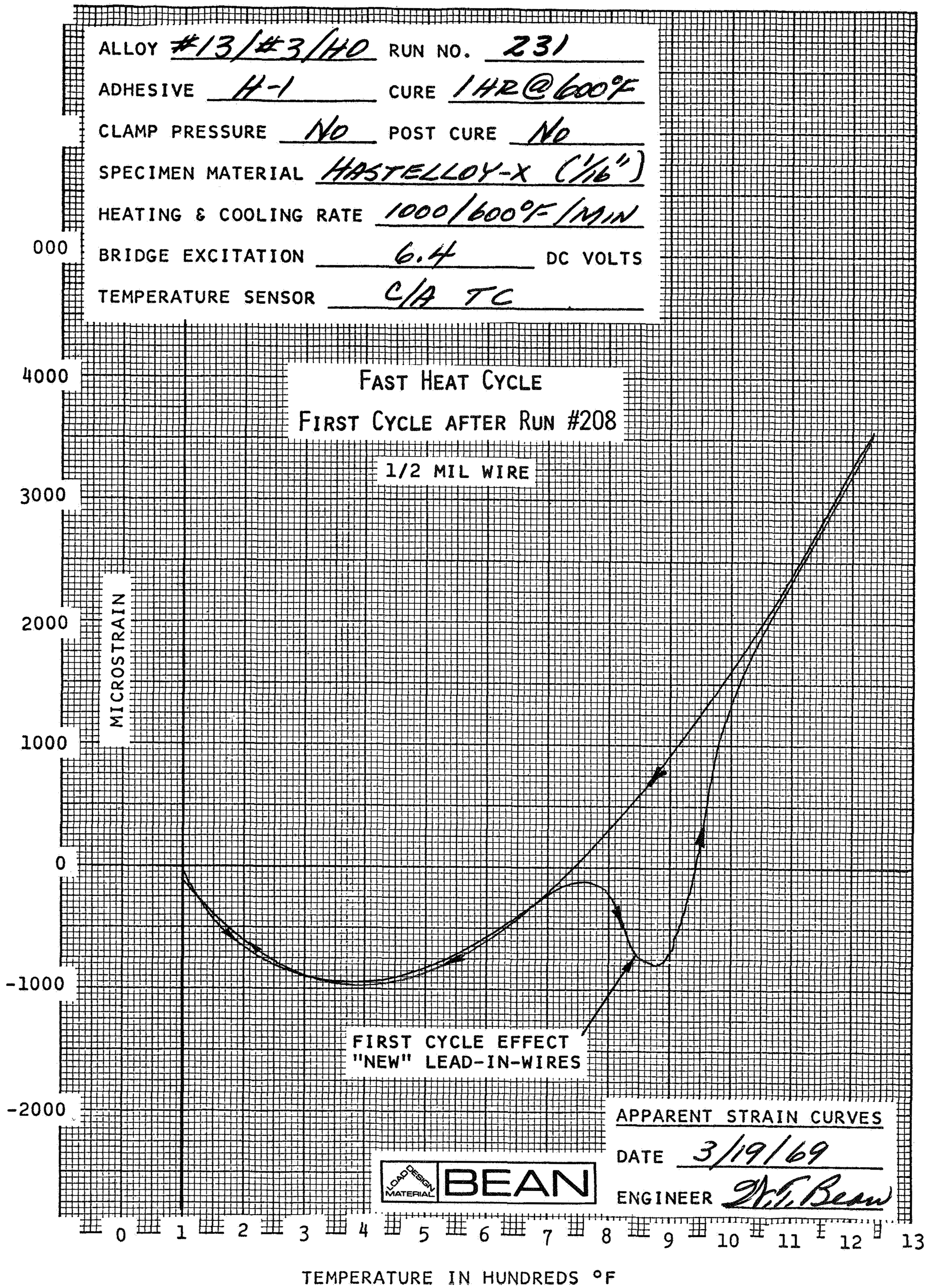
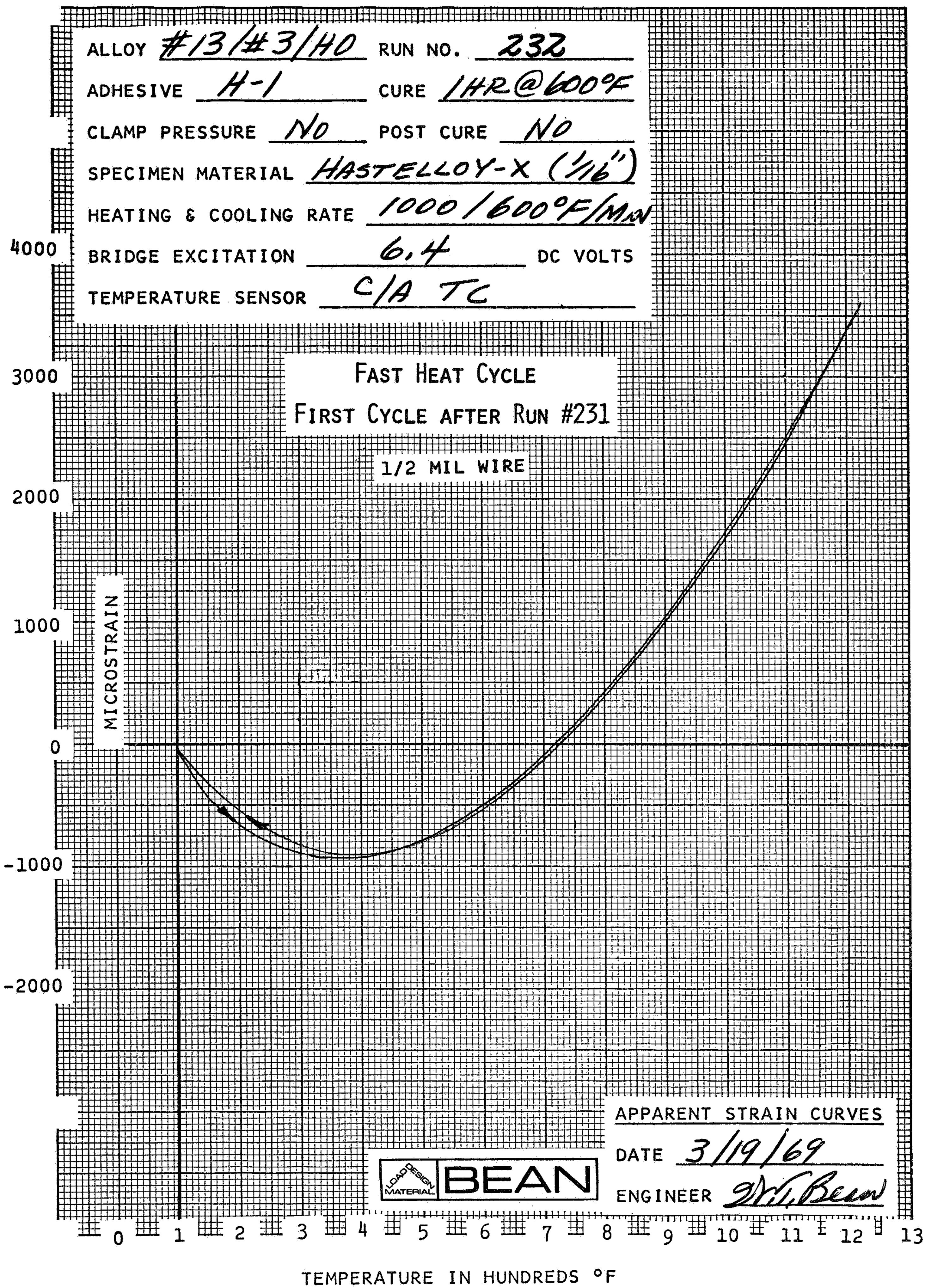

MAXIMUM HEATING & COOLING RATE
USED IN STRAIN GAGE ALLOY EVALUATION
(SEE RUNS #231 & #232)
1000°F/MIN
CURVE D
600°F/MIN
TEMPERATURE IN HUNDREDS °F
LAPSED TIME, MINUTES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
1
2
3
4
5
6
7
8
9
10
BEAN

FIGURE 17.


ALLOY #13/#3/H0
RUN NO. 231
ADHESIVE H-1
CURE 1HR@600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X (1/16")
HEATING & COOLING RATE 1000/600°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
FAST HEAT CYCLE
FIRST CYCLE AFTER RUN #208
1/2 MIL WIRE
MICROSTRAIN
000
4000
3000
2000
1000
0
-1000
-2000
FIRST CYCLE EFFECT
"NEW" LEAD-IN-WIRES
APPARENT STRAIN CURVES
DATE 3/19/69
ENGINEER W.T. Bean
LOAD DESIGN MATERIAL BEAN
0
1
2
3
4
5
6
7
8
9
10
11
12
13
TEMPERATURE IN HUNDREDS °F


ALLOY #13/#3/HO
RUN NO. 232
ADHESIVE H-1
CURE 1HR@600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X (1/16")
HEATING & COOLING RATE 1000/600°F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
FAST HEAT CYCLE
FIRST CYCLE AFTER RUN #231
1/2 MIL WIRE
MICROSTRAIN
4000
3000
2000
1000
0
-1000
-2000
0 1 2 3 4 5 6 7 8 9 10 11 12 13
APPARENT STRAIN CURVES
DATE 3/19/69
ENGINEER W. Bean
BEAN
TEMPERATURE IN HUNDREDS °F

Stability

Runs # 127 through # 130 show the results of stability tests conducted on an Alloy #13/#3 strain gage. Run # 130 logged twelve hours at 1200°F. Drift at 1200°F (as well as zero offset) vs. time is indicated. Runs # 139 and # 140 show stability tests conducted on a second specimen.

Runs # 141, # 142, # 143 show test results on a third specimen. Run # 208 was made with a strain gage employing 1/2 mil diameter wire. Figure 18 summarizes drift data.

ALLOY #13/#3 RUN NO. 127

ADHESIVE H-1 CURE 1HR @ 600°F

CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

BRIDGE EXCITATION 1.5 DC VOLTS

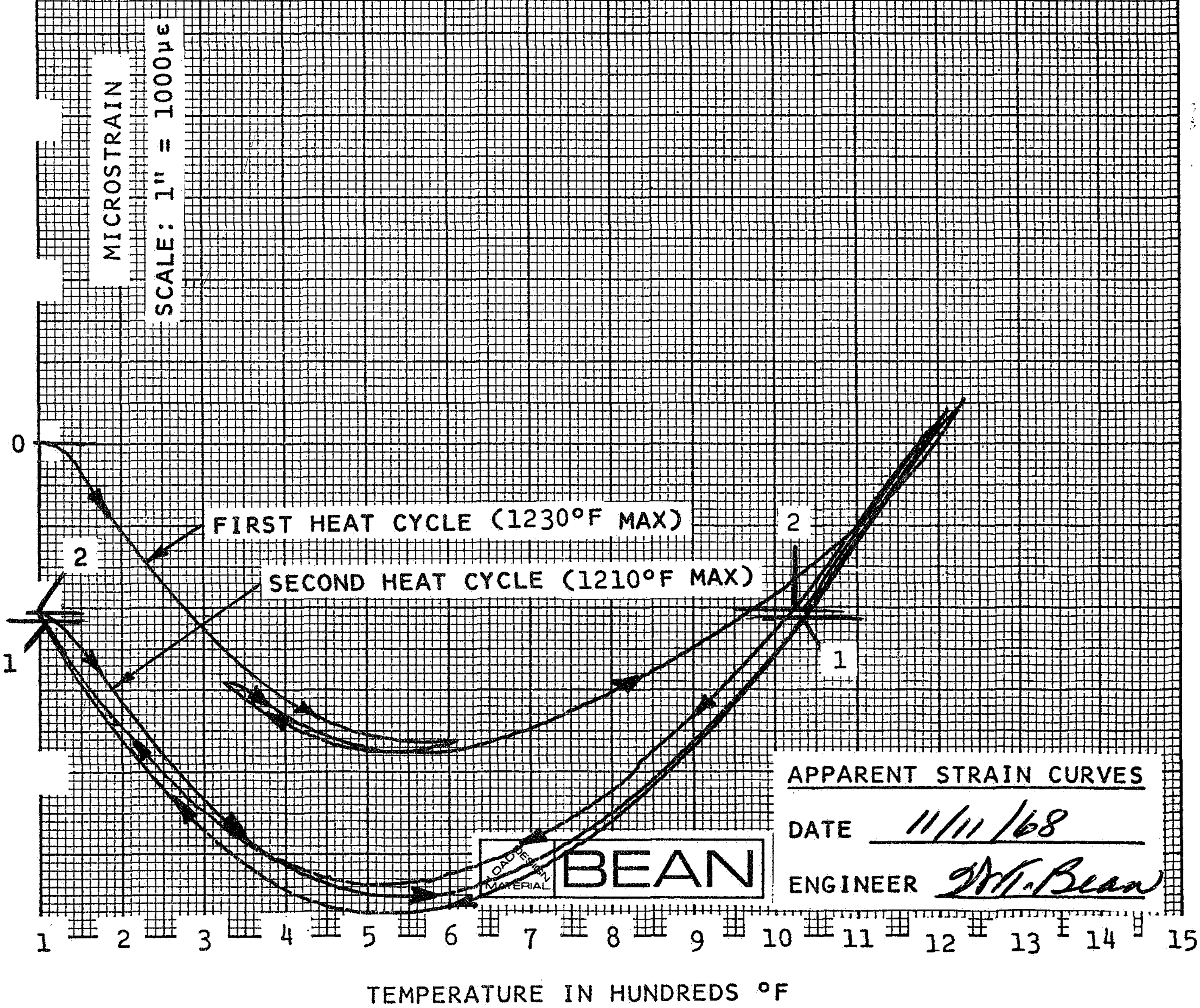
TEMPERATURE SENSOR C/A TC

2 MIL WIRE

R_{13} = 60Ω

R_3 = 20Ω

BARE WIRE STABILIZED 30 MIN @ 1275°F TO 1300°F



APPARENT STRAIN CURVES

DATE 11/11/68

ENGINEER W. Bean

ALLOY #13/#3 RUN NO. 128

ADHESIVE H-1 CURE 1HR @ 600°F

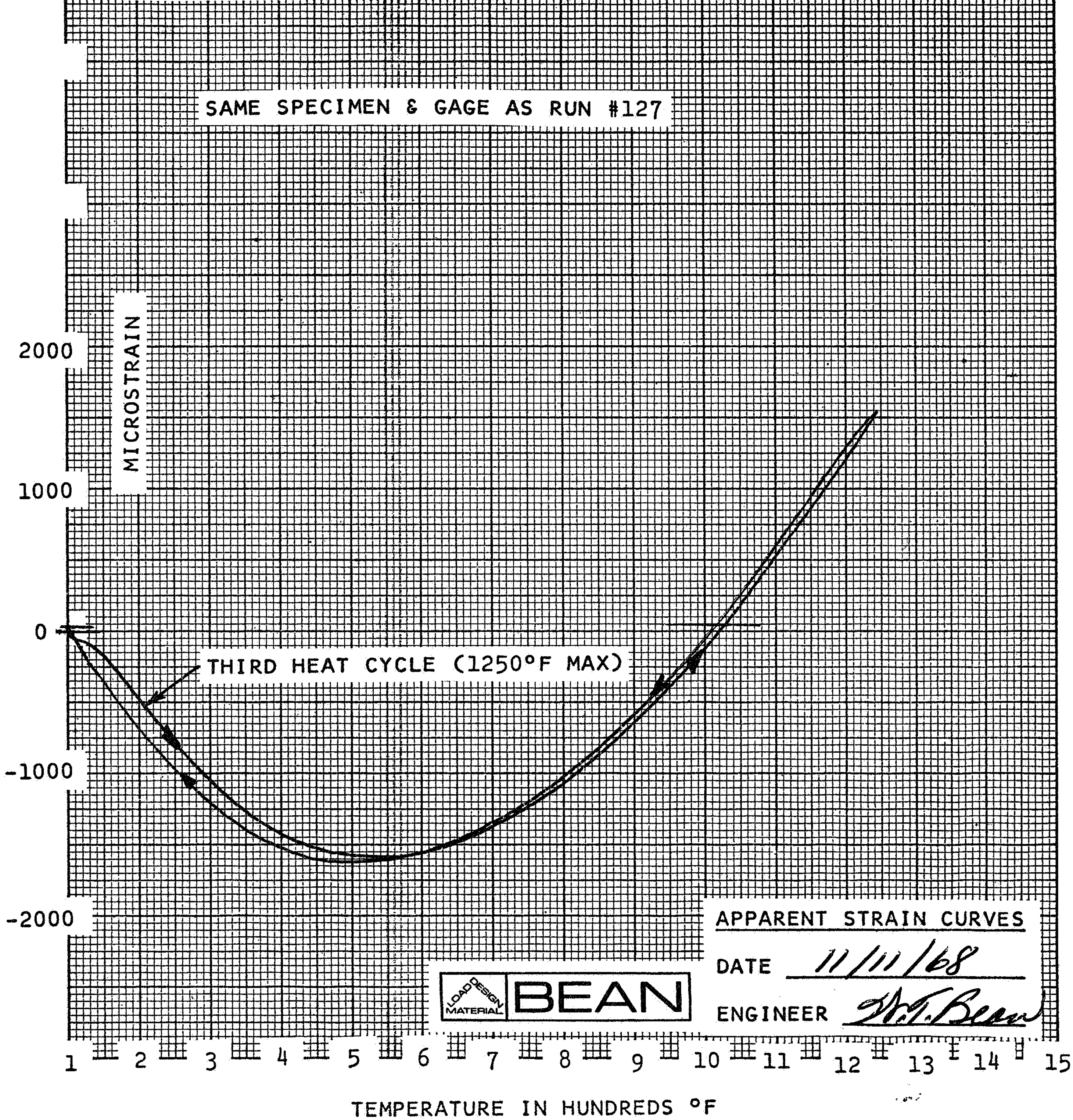
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

BRIDGE EXCITATION 1.5 DC VOLTS

TEMPERATURE SENSOR C/A TC



APPARENT STRAIN CURVES

DATE 11/11/68

ENGINEER W.T. Bean

BEAN

ALLOY #13/#3 RUN NO. 129

ADHESIVE H-1 CURE 1HR @ 600°F

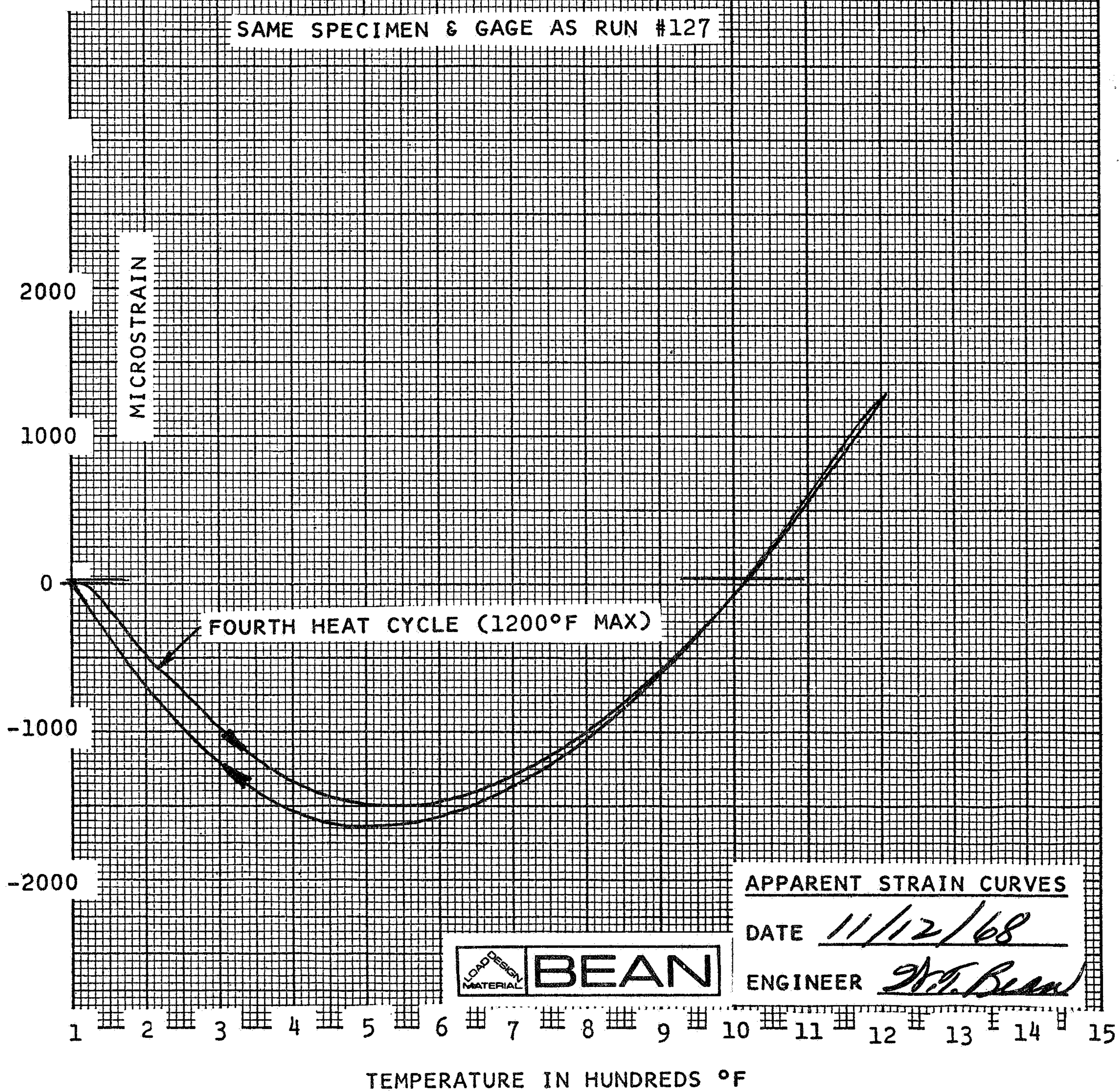
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

BRIDGE EXCITATION 1.5 DC VOLTS

TEMPERATURE SENSOR C/A TC



APPARENT STRAIN CURVES

DATE 11/12/68

ENGINEER W. T. Bean

ALLOY #13/#3 RUN NO. 130

ADHESIVE H-1 CURE 1HR @ 600°F

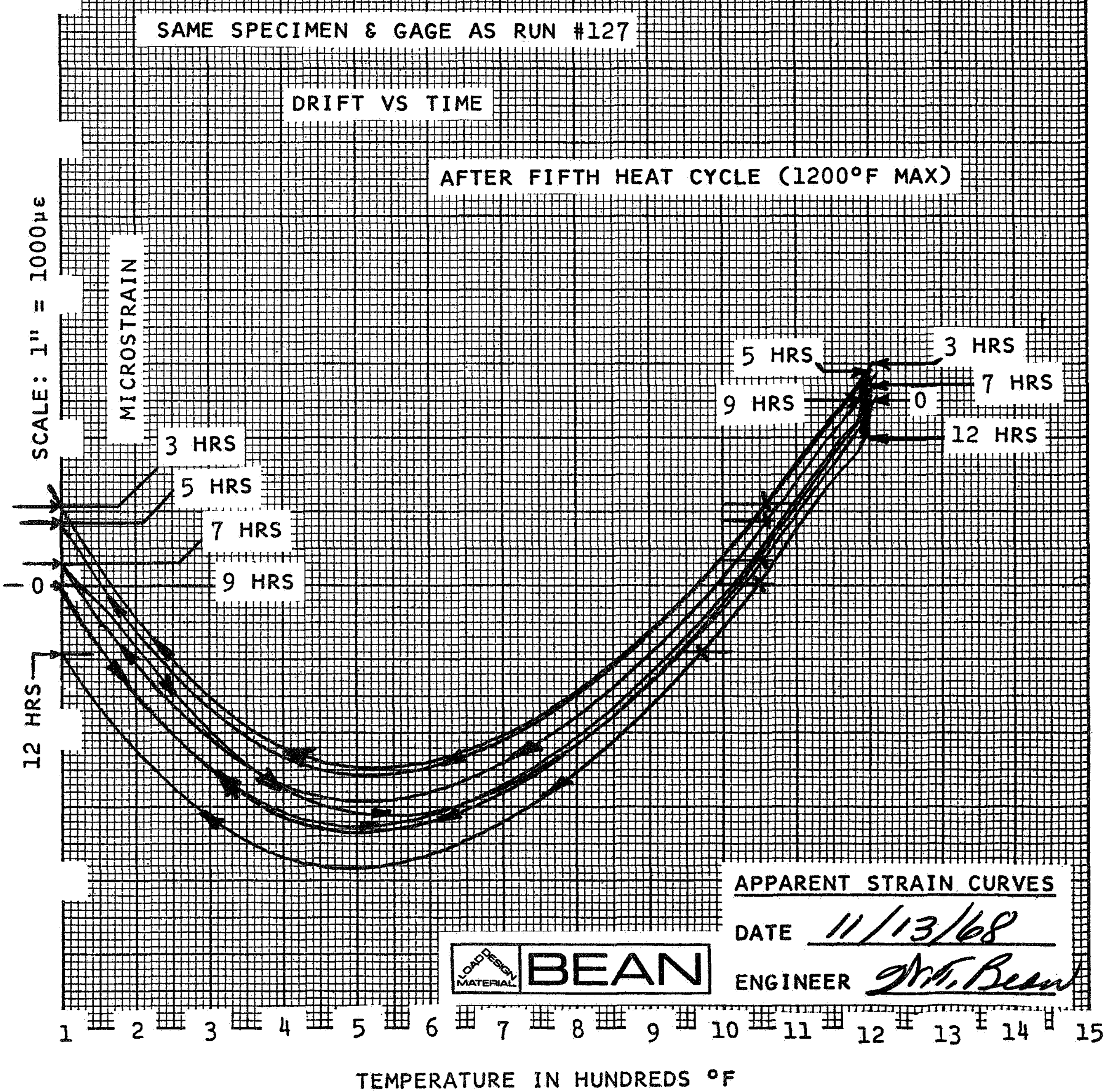
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

BRIDGE EXCITATION 1.5 DC VOLTS

TEMPERATURE SENSOR C/A TC

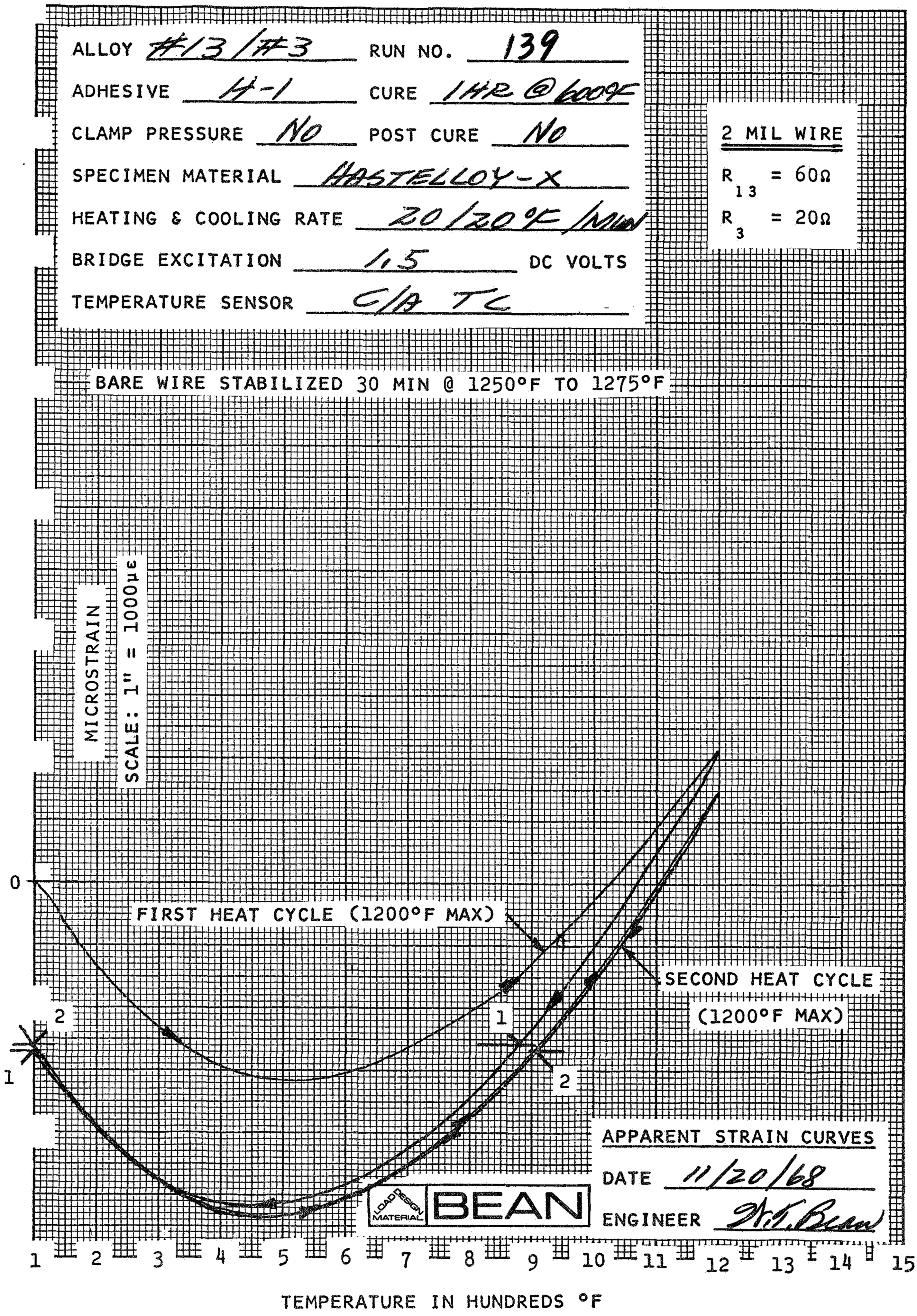


APPARENT STRAIN CURVES

DATE 11/13/68

BEAN LOAD DESIGN MATERIAL

ENGINEER W. T. Bean


ALLOY #13/#3
RUN NO. 139
ADHESIVE H-1
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 1.5 DC VOLTS
TEMPERATURE SENSOR C/A TC
2 MIL WIRE
R_{13} = 60Ω
R_3 = 20Ω
BARE WIRE STABILIZED 30 MIN @ 1250°F TO 1275°F
MICROSTRAIN
SCALE: 1" = 1000με
FIRST HEAT CYCLE (1200°F MAX)
SECOND HEAT CYCLE (1200°F MAX)
0
1
2
1
2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
TEMPERATURE IN HUNDREDS °F
APPARENT STRAIN CURVES
DATE 11/20/68
LOAD DESIGN MATERIAL BEAN
ENGINEER W.T. Bean

ALLOY #13/#3 RUN NO. 140

ADHESIVE H-1 CURE 1HR @ 600°F

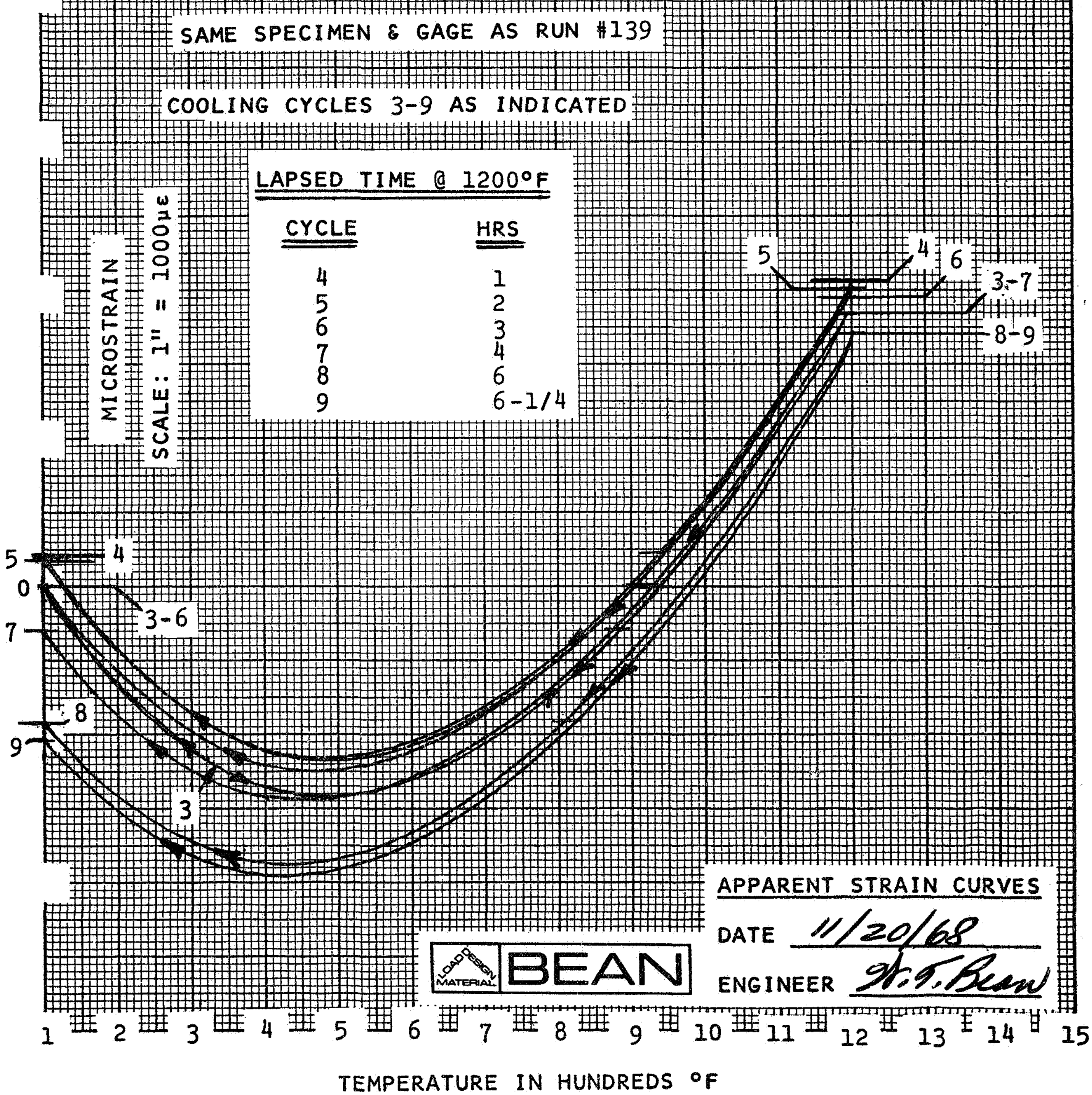
CLAMP PRESSURE No POST CURE No

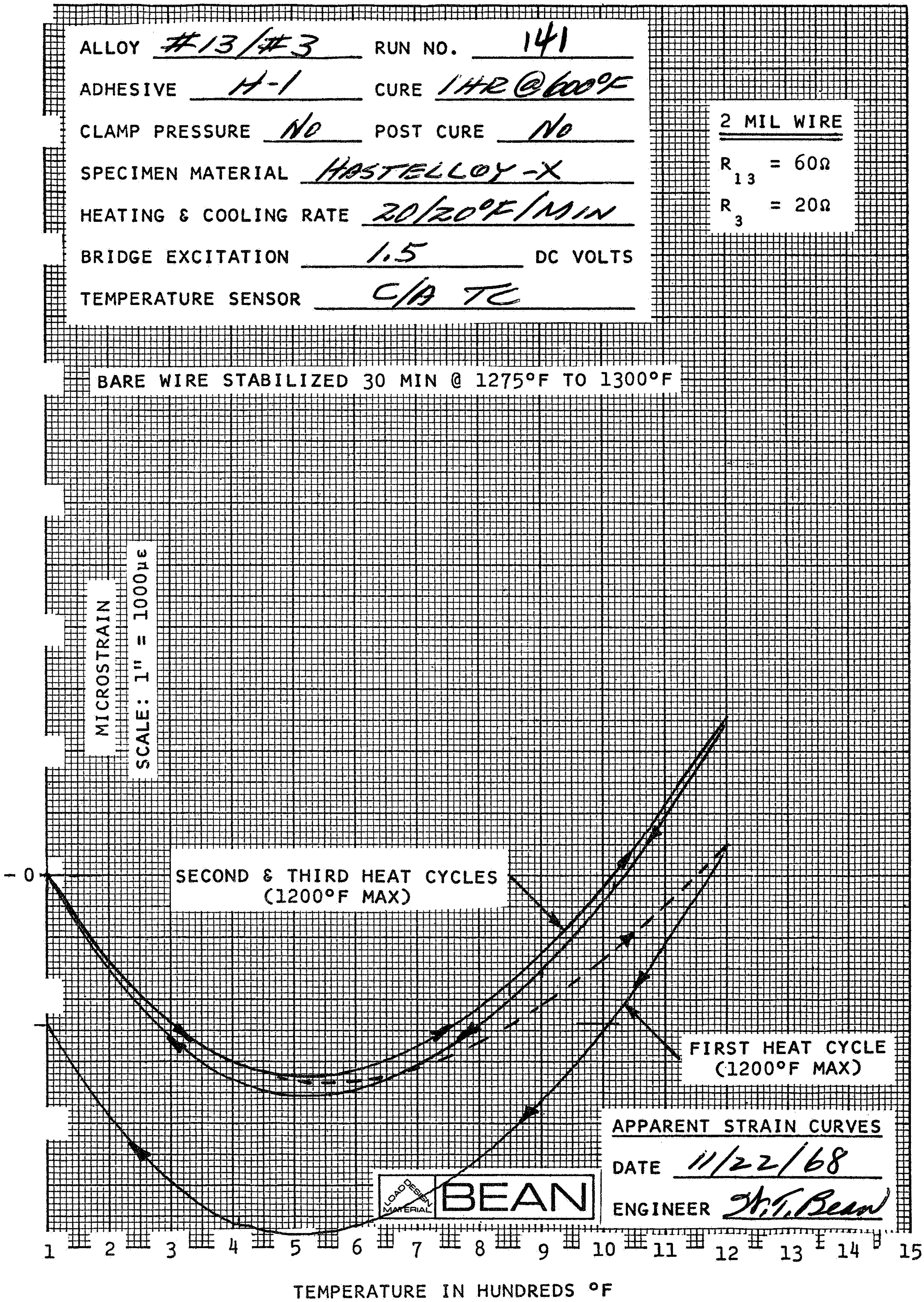
SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

BRIDGE EXCITATION 1.5 DC VOLTS

TEMPERATURE SENSOR C/A TC





ALLOY #13/#3
RUN NO. 141
ADHESIVE H-1
CURE 1HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X
HEATING & COOLING RATE 20/20°F/MIN
BRIDGE EXCITATION 1.5 DC VOLTS
TEMPERATURE SENSOR C/A TC
2 MIL WIRE
R_{13} = 60Ω
R_3 = 20Ω
BARE WIRE STABILIZED 30 MIN @ 1275°F TO 1300°F
MICROSTRAIN
SCALE: 1" = 1000με
0
SECOND & THIRD HEAT CYCLES (1200°F MAX)
FIRST HEAT CYCLE (1200°F MAX)
APPARENT STRAIN CURVES
DATE 11/22/68
ENGINEER W.T. Bean
LOAD DESIGN MATERIAL
BEAN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F

ALLOY #13/#3 RUN NO. 142

ADHESIVE H-1 CURE 1HR @ 600°F

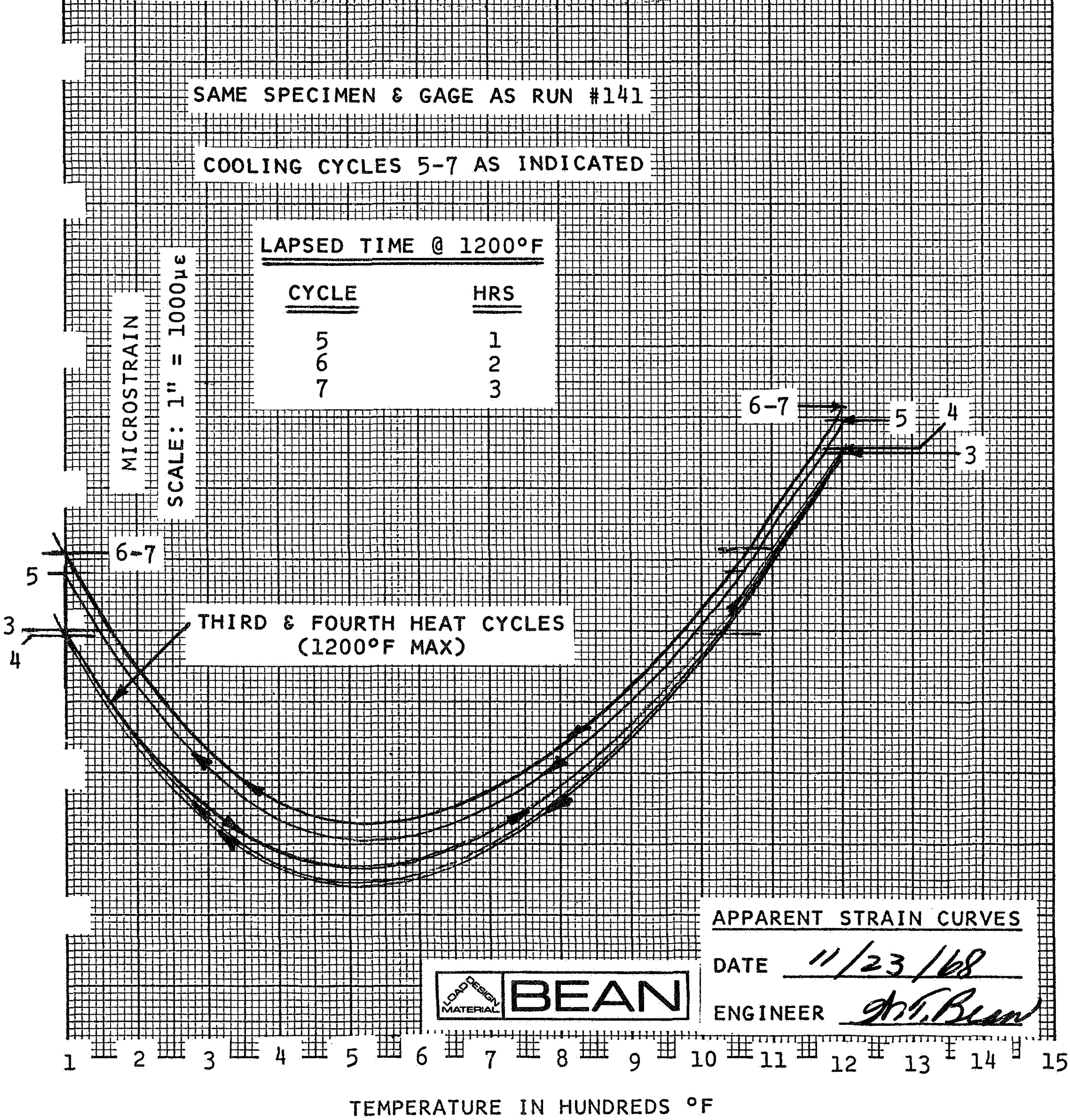
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

BRIDGE EXCITATION 1.5 DC VOLTS

TEMPERATURE SENSOR C/A TC



APPARENT STRAIN CURVES

DATE 11/23/68

BEAN LOAD DESIGN MATERIAL

ENGINEER W. T. Bean

ALLOY #13/#3 RUN NO. 143

ADHESIVE H-1 CURE 1HR@600°F

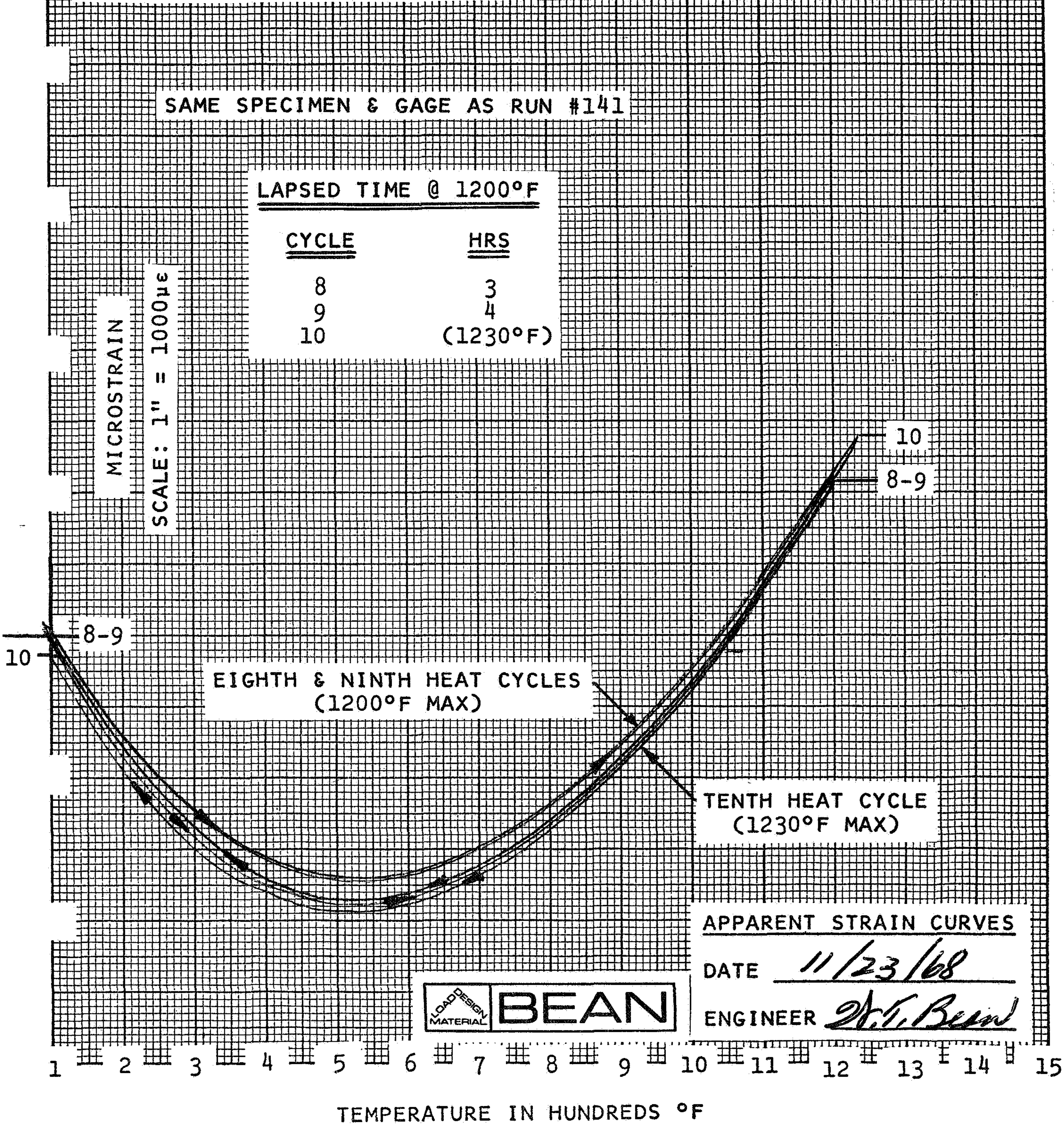
CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

BRIDGE EXCITATION 1.5 DC VOLTS

TEMPERATURE SENSOR C/A TC

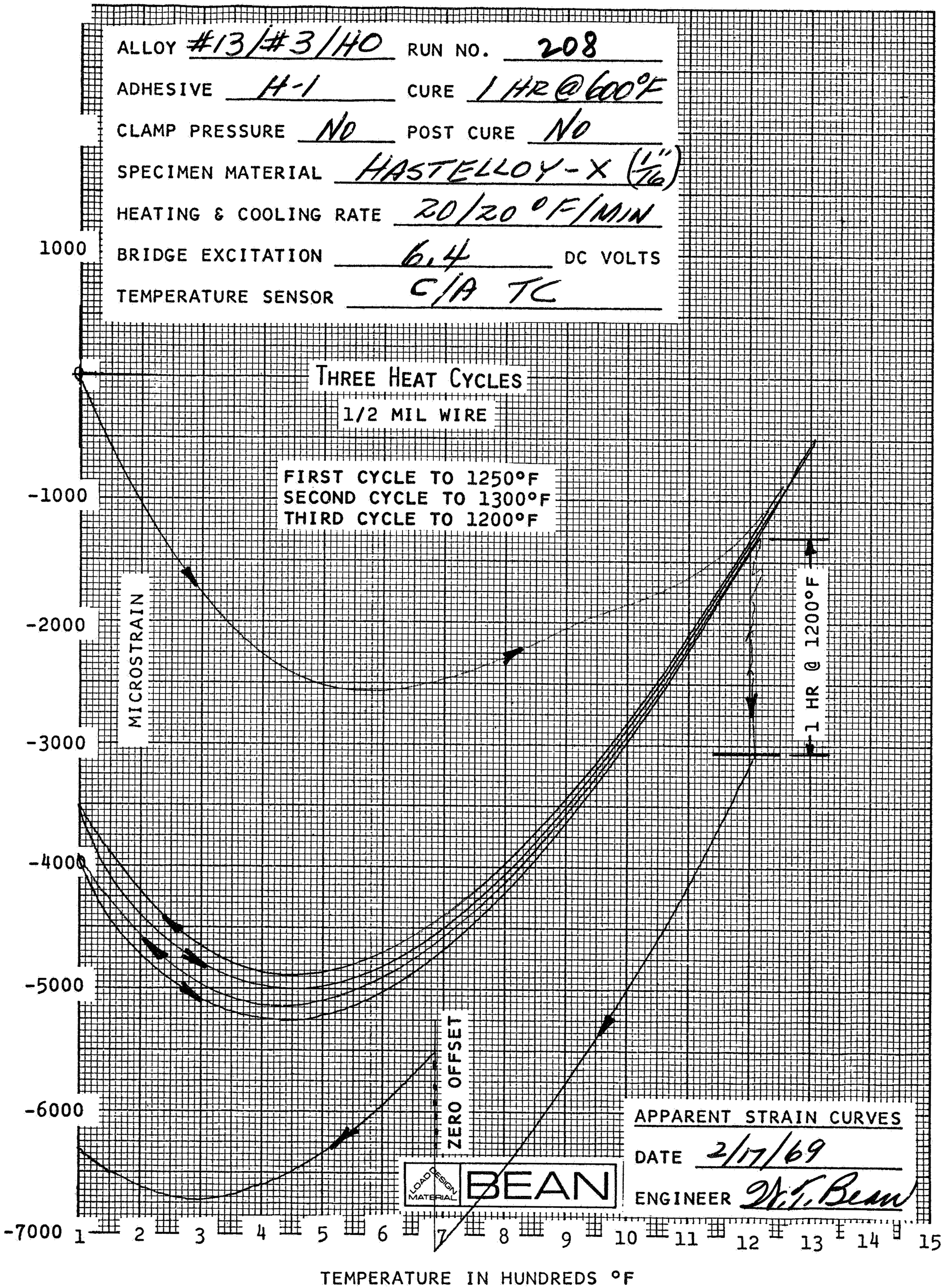


APPARENT STRAIN CURVES

DATE 11/23/68

ENGINEER W.T. Bean

LOAD DESIGN MATERIAL BEAN



ALLOY #13/#3/HO
RUN NO. 208
ADHESIVE H-1
CURE 1 HR @ 600°F
CLAMP PRESSURE NO
POST CURE NO
SPECIMEN MATERIAL HASTELLOY-X (1/16")
HEATING & COOLING RATE 20/20 °F/MIN
BRIDGE EXCITATION 6.4 DC VOLTS
TEMPERATURE SENSOR C/A TC
THREE HEAT CYCLES
1/2 MIL WIRE
FIRST CYCLE TO 1250°F
SECOND CYCLE TO 1300°F
THIRD CYCLE TO 1200°F
1 HR @ 1200°F
MICROSTRAIN
ZERO OFFSET
1000
-1000
-2000
-3000
-4000
-5000
-6000
-7000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TEMPERATURE IN HUNDREDS °F
APPARENT STRAIN CURVES
DATE 2/17/69
ENGINEER W.T. Bean
LOAD DESIGN MATERIAL
BEAN

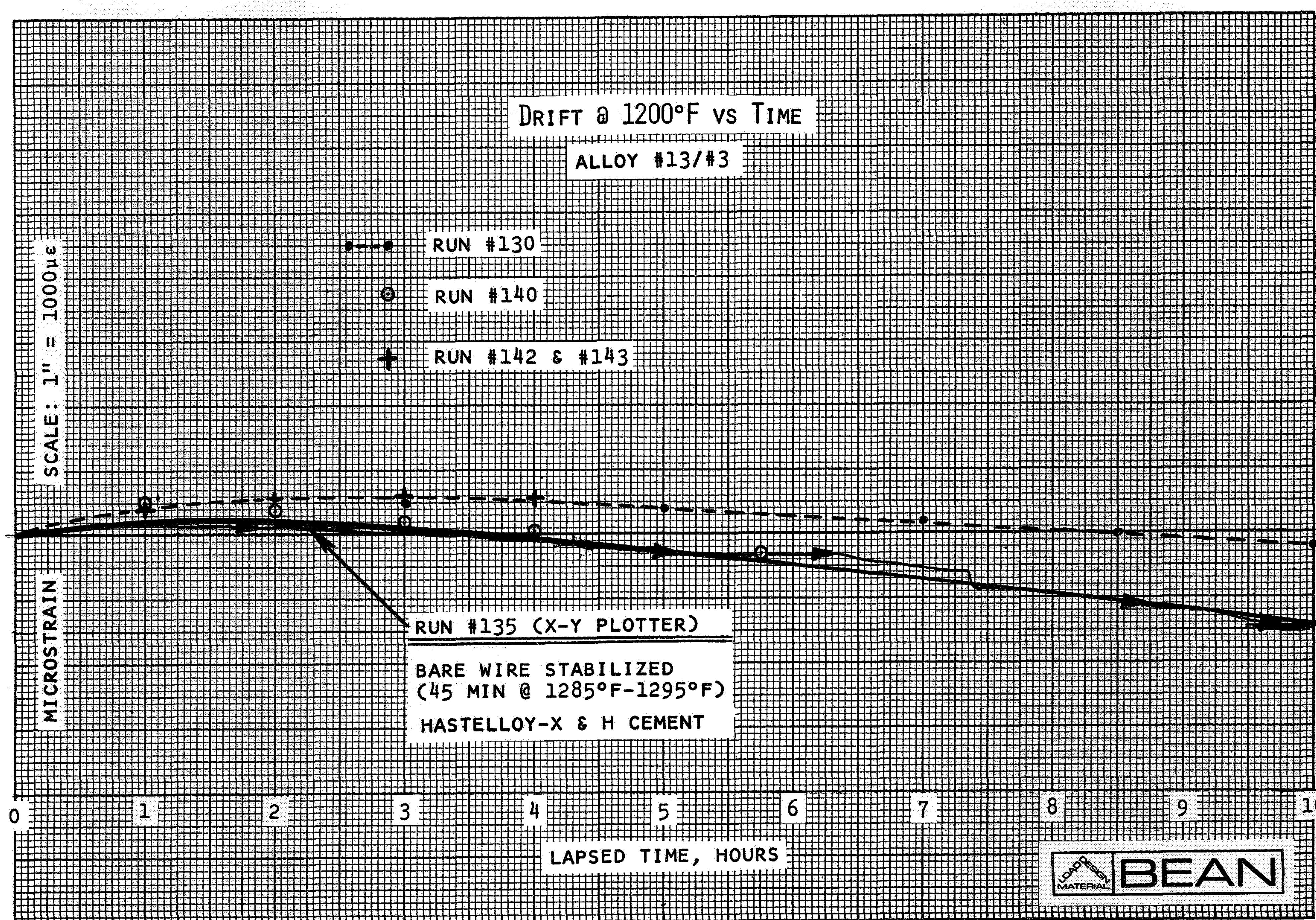

DRIFT @ 1200°F VS TIME
ALLOY #13/#3
RUN #130
RUN #140
RUN #142 & #143
RUN #135 (X-Y PLOTTER)
BARE WIRE STABILIZED
(45 MIN @ 1285°F-1295°F)
HASTELLOY-X & H CEMENT
SCALE: 1" = 1000µε
MICROSTRAIN
0
1
2
3
4
5
6
7
8
9
10
LAPSED TIME, HOURS
LOAD DESIGN MATERIAL BEAN

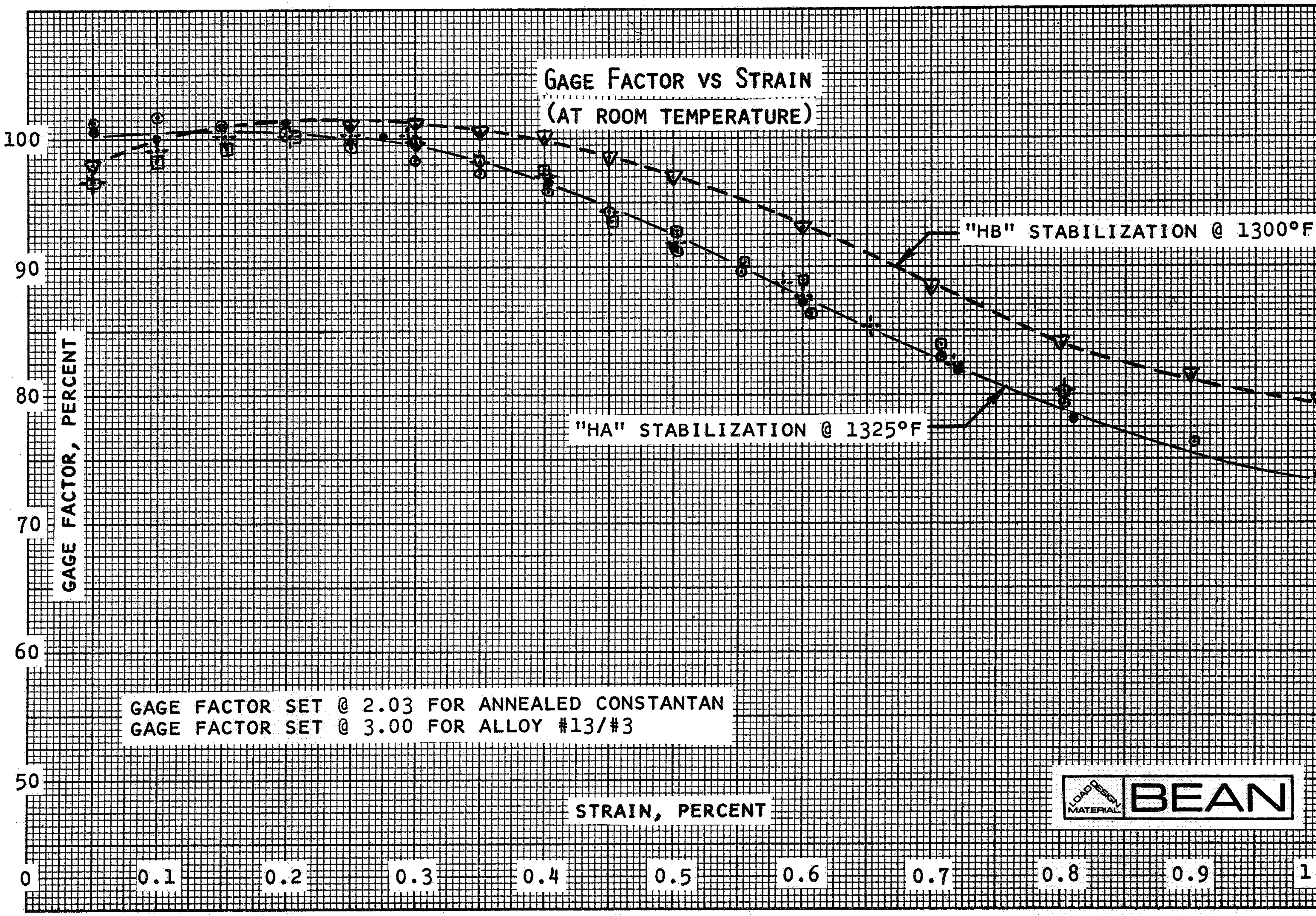
FIGURE 18.

Gage Factor vs. Strain

Several gage factor vs. strain tests were conducted by mounting the Alloy #13/#3 gage on annealed aluminum bars (1/4" x 1" x 12").

Room temperature curing epoxies, heat curing epoxies, phenolics, and ceramic adhesives were employed. A constant-moment section for the strain gage was established by the loading fixture. An annealed constantan gage was mounted on the beam for comparative purposes.

The test results are shown in Figure 19. While the gage factor decreases with increasing strain as indicated, the captive filament will yield 100% gage factor on the recovery (relaxation) cycle and subsequent cycles.



GAGE FACTOR VS STRAIN
(AT ROOM TEMPERATURE)
"HB" STABILIZATION @ 1300°F
"HA" STABILIZATION @ 1325°F
GAGE FACTOR SET @ 2.03 FOR ANNEALED CONSTANTAN
GAGE FACTOR SET @ 3.00 FOR ALLOY #13/#3
GAGE FACTOR, PERCENT
STRAIN, PERCENT
100
90
80
70
60
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
LOAD DESIGN MATERIAL
BEAN

FIGURE 19.

VII. CONCLUSIONS

All "Superalloys" tested contained significant amounts of nickel and chromium and exhibited solid solution phase changes below the 1200°F operating range. A change in the solid solution results in an anomaly of the resistance vs. temperature curve and yields an unsatisfactory alloy for high-temperature strain gage usage.

Alloy # 5, however, can be considered for high-temperature dynamic work and should result in a strain gage filament superior to those currently being used in the vibratory testing of turbine blades.

Alloy #13/#3 yields a strain gage that is suitable for the measurement of steady-state strains up to 1200°F and is feasible for commercial production.

Alloy # 3 is more stable at elevated temperature than Alloy # 13.

Alloy # 4 should be evaluated as a compensating filament.

VIII. RECOMMENDATIONS

Alloys of platinum containing palladium-molybdenum should be investigated with a view toward:

1. Obtaining an improvement in the stability of the active filament (above 1000°F).
2. Achieving a more linear temperature coefficient of resistance. This will result in a more satisfactory apparent strain curve.
3. Increasing the coefficient of expansion in order to obtain better first cycle performance on high-expansion materials.
4. Reduction in gage factor. The judicious use of the proper compensating filament also would result in a more linear gage factor vs. strain.